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FINAL REPORT

1 ~~May~~ June, 1985 - 31 May, 1988

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Table of Contents

PAPERS SUBMITTED/PROCESSED/PUBLISHED UNDER PRIOR

CONTRACT DAAG29-82-K-0142

* P.V. Kumar, R.A. Scholtz, and L.R. Welch, "Generalized Bent Functions and Their Properties", *Journal of Combinatorial Theory, Series A*, Vol. 40, No. 1, September, 1985, pp. 90-107.

* 20 reprints 1/86

****

* C.L. Weber and E. Siess, "Acquisition of Direct Sequence Signals with Modulation and Jamming", *IEEE Journal on Selected Areas in Communications*, vol. SAC-4, no. 2, pp. 254-272, March, 1986.

* 20 reprints 7/86

A B S T R A C T

The effects of data modulation and/or narrowband interference on the acquisition time of direct sequence (DS) systems are assessed when particular acquisition schemes are selected. Finally, the results of these analyses are used to propose receivers which mitigate the deleterious effects of the data or jamming.

The analyses demonstrate that the I-Q detector, modified for a data modulated carrier, is superior to the correlator/square-law detector despite the latter's robustness to data. When the average pulsed jammer power is constrained, the analyses illustrate that the jammer's duty factor does not impact acquisition time when the pulse repetition frequency (PRF) is high; a duty factor of unity maximally degrades acquisition performance when the PRF is low.

A proposed adaptive receiver provides considerable jamming protection; the acquisition performance of such a receiver bounds the performance of all adaptive acquisition receivers.

****

* A. Polydoros and C.L. Weber, "Analysis and Optimization of Correlative Code-Tracking Loops in Spread-Spectrum Systems," *IEEE Transactions on Communications*, vol. COM-33, no. 1, January, 1985.

* 20 reprints 1/86

****

* A. Reichman and R.A. Scholtz, "Adaptive Spread Spectrum Systems Using Least Squares Lattice Algorithm," *IEEE Journal on Selected Areas in Communications*, vol. SAC-3, no. 5, September 1985.

* 20 reprints 1/86

****

* N.K. Huang, L.R. Welch, and R.A. Scholtz, "Markov Texture Model for Automatic Segmentation," submitted to the *IEEE Transactions on Pattern Analysis and Machine Intelligence*.

* 1 preprint sent with previous report

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* A. Netch and R.A. Scholtz, "Pairwise Coupled RDA Antennas for Self-Focusing and Retrodirective Antennas," presentation at *1985 International Symposium on Information Theory*, Brighton, England, June 1985.

* 1 preprint sent with previous report

****

* S. Soliman and R.A. Scholtz, "Autocorrelation Ambiguity Functions," *Globecom '85 Record*, New Orleans, LA, December 2-5, 1985, paper 16.3.

* 20 reprints 1/86

A B S T R A C T

An ambiguity function, different from the well known Woodward ambiguity function, is defined and its properties are derived. These functions are shown to be an aid for selecting good signals to be used when dealing with doubly spread targets. The relationship between the auto-correlation ambiguity function and the Woodward ambiguity function for different models of targets is developed. Finally, measures of rms correation time and rms correlation bandwidth for non-stationary processes are defined.

PAPERS SUBMITTED/PROCESSED/PUBLISHED DURING THIS PERIOD

* John R. Alexovich and Robert M. Gagliardi, "Frequency Synthesizer Transient Effects in FH-FSK," *Proceedings of MILCOM'86*, Monterey, CA, October 1986.

* 20 reprints 1/87

ABSTRACT

Agile frequency synthesizers have been proposed for accomplishing the frequency-hopping and dehopping in FH-FSK communications. Since the design of such synthesizers generally involve divide-down phase-lock loops, transients exist that limit the ability of the loop to hop rapidly over the hopping band. These transients lead to effective energy loss that degrades the resulting decoding performance. In this paper, hopping transients are studied in terms of their dynamical equations, their relation to key loop parameters, and their effect on decoding operations. The importance of pre-tuning is shown. Suggested techniques to combat the transient loss, as delaying the decoder integration start-time, or ping-ponging two synthesizers, are evaluated.

****

* Robert M. Gagliardi and John Alexovich, "Spur Veneration in Wideband High-Resolution Frequency-Hopping Synthesizers," *Proceedings of MILCOM '86*, Monterey, Ca., October 1986.

* 20 reprints 1/87

ABSTRACT

Frequency generators using commandable divide-down control of VCO's have been developed for accomplishing highly accurate rapid frequency hopping in most types of frequency hopped (FH) communications. Recently several modifications to such synthesizers have been proposed to improve hopping performance, such as saw-tooth phase detection (for improved tracking range), and reference mixers (for increased hopping accuracy and resolution). However, these modifications all suffer from a basic problem of generating unwanted spur lines that can circulate within the synthesizer. These lines can then modulate the output VCO, producing additional spectral lines around the true hopping frequency. Such modulation lines are particularly bothersome to FS-FSK formats, where modulation tones can produce unwanted mixing into incorrect frequency bins during decoding.

This paper presents the results of a study to examine spur generating in wide band, high resolution frequency synthesizers. The objective is to identify causes of spur origination, their effects on system performance and methods for their control and elimination. The relation of spur amplitudes to specific loop parameters is derived,

allowing output spur levels to be presented. Techniques to reduce spur levels in these systems is also addressed.

* J. Alexovich and R. Gagliardi, "Frequency Synthesizer Effects in FSK Frequency Hopped Communications", accepted for publication *IEEE Trans. on Communications*, 1988.

* 1 preprint 12/87

A B S T R A C T

Agile frequency synthesizers are the common device used for commandable, wide-band frequency hopping in frequency hopped (FH) communications. Since the design of such synthesizers involves divide-down phase lock loops, transients exist that limit the ability of the loop to hop rapidly. These transients lead to effective energy loss that degrades resulting decoding performance. In addition, synthesizers may employ digital phase detectors and digital frequency generators for improved resolution. These modifications often introduce unwanted spurs that can appear at the hopping output as unwanted spectral lines. In this paper synthesizer transient and spur effects in an FSK FH system is investigated. Models for transient analysis are developed, and resulting degradations to performance are computed. Compensation methods, such as ping-ponging and bit integration delay are considered. A spur analysis is presented, and the overall output effects on hopping spectrum and decoding is shown. Methods to bound degradation in terms of number and strength of spur lines are presented.

****

* John Alexovich and Robert Gagliardi, "Effect of PLL Frequency Synthesizer in FSK Frequency Hopped Communications", accepted for publication *IEEE Transactions on Communications*, 1988.

* 1 preprint 6/38

A B S T R A C T

Agile frequency synthesizers are the common device used for commandable, wideband frequency hopping in frequency hopped (FH) communications. When the design of such synthesizers involve divide-down phase lock loops, transients exist that limit the ability of the loop to hop rapidly. These transients lead to effective energy loss that degrades resulting demodulation performance. In addition, phase locked synthesizers may employ digital phase detectors and direct digital synthesizers for improved resolution. These modifications often introduce unwanted spurs that can appear at the hopping output as unwanted spectral lines. In this paper, synthesizer transient and spur effects in an FSK-FH system are investigated. Models for transient analysis are developed, and resulting degradations to performance are computed. Compensation methods, such as ping-ponging multiple synthesizers and gating symbol detectors, are considered. A spur analysis is presented, and the overall output effects on hopping spectrum and demodulation are shown. Methods to bound degradation in terms of number and strength

of spur lines are presented.

****

* Lloyd J. Griffiths, "A New Approach to Partially Adaptive Arrays", *Proceedings IEEE ASSP*, pp. 1999-2002, 1987.

*

20 reprints 7/87

ABSTRACT

When an adaptive array operates in the presence of white noise only, the resulting beam pattern is referred to as the quiescent response. Typically, these patterns have mainlobe and sidelobe shapes differing from those designed for use in deterministic, non-adaptive arrays. This paper describes a simple method which allows nearly arbitrary specification of the quiescent response in a linearly-constrained power minimization adaptive array. The only restriction on the quiescent is that it must meet the constraints defined for the adaptive array. Since many well-known deterministic designs such as Chebychev are not likely to meet the linear constraint conditions used in adaptive arrays for mainlobe and other pattern control functions, a procedure is presented which modifies the deterministic design to force it to meet the linear constraints in a least-squares manner. Once this has been accomplished, the methods outlined in this paper can be used to cause the modified deterministic design to become the quiescent response of the adaptive array. As a result, the adaptive array can be configured to closely resemble a deterministic array when the noise is white. Under conditions of correlated interference, or jamming, however, the response changes so as to effectively steer nulls in the appropriate directions. The method is based on the use of a generalized sidelobe canceller and requires one additional linear constraint for both narrow-band and broad-band arrays. This added flexibility in a partially adaptive array allows the system to be configured so as to meet an arbitrary number M of linear constraints either at all times (using M degrees of freedom) or only under quiescent conditions (using a single constraint). Any intermediate mixture of these extreme positions is also possible.

****

* Kevin M. Buckley and Lloyd J. Griffiths, "Design of Deterministic Beamformers for Arbitrarily Configured Arrays", *Proc. ICASSP-87*, Dallas, Texas, April 1987, pp 47.1.1-4.

*

20 reprints 7/87

ABSTRACT

Design of deterministic (fixed) beamformers for arbitrarily configured, narrow-band and broad-band arrays is addressed in this paper. A least squares procedure is described which is based on the formulation and solution of a set of *eigenvector constraint equations*. The constraints are employed to effectively specify array/beamformer response for selected *pass-band regions* of source location and frequency parameters. For broad-band beamformer design, the design procedure results in improved response control compared to narrow-band decomposition design approaches. Additionally, a procedure for evaluating the plausibility of a response specification is described.

****

* Lloyd J. Griffiths, and Kevin M. Buckley, "Quiescent Pattern Control in Linearly-Constrained Adaptive Arrays," *ASSP Transactions*, vol. ASSP-35, no. 7, pp. 917-926 July 1987.

* 20 reprints 12/87

ABSTRACT

When an adaptive array operates in the presence of white noise only, the resulting beam pattern is referred to as the quiescent response. Typically, these patterns have mainlobe and sidelobe shapes differing from those designed for use in deterministic, non-adaptive arrays. This paper describes a simple method which allows nearly arbitrary specification of the quiescent response in a linearly-constrained power minimization adaptive array. The only restriction on the quiescent is that is must meet the constraints defined for the adaptive array. Since many well-known deterministic designs such as Chebychev are not likely to meet the linear constraint conditions used in adaptive arrays for mainlobe and other pattern control functions, a procedure is presented which modifies the deterministic design to force it to meet the linear constraints in a least-squares manner. Once this has been accomplished, the methods outlined in this paper can be used to cause the modified deterministic design to become the quiescent response of the adaptive array. As a result, the adaptive array can be configured to closely resemble a deterministic array when the noise is white. Under conditions of correlated interference, or jamming, however, the response changes so as to effectively steer nulls in the appropriate directions. The method is based on the use of a generalized sidelobe canceller and requires one additional linear constraint for both narrow-band and broad-band arrays.

****

* T.C. Hou and Victor O.K. Li, "Transmission Range Control in Multihop Packet Radio Networks," *IEEE Transactions on Communications*, Vol.

COM-34, No. 1, January 1986, pp. 38-44.

* 20 reprints 7/86

A B S T R A C T

This paper presents a model for analyzing the performance of transmission strategies in a multihop packet radio network where each station has adjustable transmission radius. A larger transmission radius will increase the probability of finding a receiver in the desired direction and contribute bigger progress if the transmission is successful, but it also has a higher probability of collision with other transmissions. The converse is true for shorter transmission range. We illustrate our model by comparing three transmission strategies. Our results show that the network can achieve better performance by suitably controlling the transmission range. One of the transmission strategies, namely transmitting to the nearest forward neighbor by using adjustable transmission power, has desirable features in a high terminal density environment.

****

* S.L. Su and Victor O.K. Li, "An Iterative Model to Analyze Multihop Packet Radio Networks", *Proceedings of the Allerton Conference on Communications, Control, and Computing*, Monticello, Illinois, October 1985.

* 20 reprints 1/86

A B S T R A C T

A performance model of a slotted multihop Packet Radio Network is presented. The message generation processes at the nodes are assumed to be independent Bernoulli processes. A node may transmit or receiver, but not both at the same time. The transmission queue at each node is modeled as a discrete-time Markov chain. The dependencies of the transmission queues at different nodes are assumed to be characterized by certain parameters of these Markov chains. An iterative procedure is developed to solve for these parameters. Several different transmission protocols will be considered. We have used our model to analyze both narrowband Slotted ALOHA and code division multiple access spread spectrum networks. In the example networks that we have considered, the analytic results match the simulation results very closely.

****

* T.C. Hou and Victor O.K. Li, "Position Updates and Sensitivity Analysis for Routing Protocols in Multihop Mobile Packet Radio Networks," *Proceedings of IEEE GLOBECOM '85*, New Orleans, LA, December 1985.

* 20 reprints 1/86

A B S T R A C T

A communication network consisting of a large number of geographically dispersed, mobile nodes is considered. Due to the limited transmission power of the nodes, a

message must be relayed from node to node before it reaches its destination. Therefore, routing strategies are necessary. Position location and updating are required for some routing strategies in multihop mobile Packet Radio Network. Two distributed position update schemes are proposed. The effect of inaccurate positions, which results from update delays on network performance is studied for a network using the MFR routing strategy.

****

* S.L. Su and Victor O.K. Li, "Time Synchronization and Ranging for Multihop Mobile Radio Networks," *Proceedings of IEEE INFOCOM '86*, Miami, Florida,, April 1986.

* 20 reprints 7/86

A B S T R A C T

We propose an efficient algorithm to synchronize geographically distributed nodes in a multihop mobile radio network which uses spread spectrum signals for communication. This synchronism requires the synchronization of the clocks at all nodes and accurate measurements of the distance between them. The distances must be updated periodically to reflect changes in the nodes' locations.

****

* Szu-Lin Su and Victor O.K. Li, "Performance Comparison of Acknowledgement Protocols for Multihop Code Division Multiple Access Networks," *Proceedings of ICC '86*, Toronto, Ontario, Canada, June 1986.

* 20 reprints sent 5/86

A B S T R A C T

In this paper, three acknowledgement protocols are proposed for multihop Code Division Multiple Access (CDMA) networks. Time is divided into fixed length slots. Under Protocol 1, the length of each time slot is equal to the transmission time of a data packet and an acknowledgement (ACK) packet. The ACK will be sent immediately following a successful data packet transmission. Under Protocol 2, the length of each time slot is equal to the length of a data packet transmission. The time slot immediately following a transmission will be reserved for the ACK packet. The length of a time slot in Protocol 3 is the same as that in Protocol 1. However, the ACK packet will be used to acknowledge the data packet transmission in the previous slot, and the starting time of the ACK within the slot is randomized. The throughput/delay performance of these three protocols in multihop CDMA networks with buffered nodes are analyzed. It is shown that Acknowledgement Protocol 3 is the best choice for a wide range of network operational scenarios.

****

* Mohsen Sarraf and Victor O.K. Li, "An Adaptive Multiple Access Strategy for a Channel with Power Capture," *Proceedings of ICC '86*, Toronto, Ontario, Canada, June 1986.

* 20 reprints 5/86

ABSTRACT

We consider a communication channel which is shared by two classes of stations, the Dominating Class (DC) and the Non-Dominating Class (NDC). The DC stations transmit at a higher power than the NDC stations. Due to the capture effect, a transmission will be received successfully if no other transmissions at the same or higher power is transmitted at the same time. It can be shown that, in order to allow some of the NDC transmissions to get through and hence maximize the total channel throughput, the DC stations have to send at a rate which is lower than the optimal rate (in the absence of the NDC stations). However, if the NDC stations use the channel at a time-varying rate, due to changes in their traffic requirements, the DC stations shall adjust their rates accordingly. We will develop a scheme in which the DC stations estimate the transmission rate of the NDC stations and switch between different rates, for an optimal total throughput.

****

* Mohsen Sarraf and Victor O.K. Li, "A Stable Multiple Access Scheme for Satellite Communications Networks," *Proceedings INFOCOM '86*.

* 20 reprints 5/86

ABSTRACT

This paper develops a new multiple access scheme for satellite communications networks. Under this scheme, newly generated traffic are transmitted as in the ALOHA scheme, but retransmissions, if necessary, are preassigned to specific time slots. This new algorithm is relatively simple to implement, is stable, and offers throughput in the 0.5 to 0.6 range with bounded maximum average delay. A modification of this basic algorithm which exploits power capture is also developed. This modified algorithm outperforms slotted-ALOHA, TDMA, as well as most of the existing algorithms, under all traffic situations, both in terms of throughput and delay.

****

* Mohsen Sarraf & Victor Li, "Carrier-Sense Multiple Access with Fixed

Retransmission Assignment", *Proceedings IEEE GLOBECOM*, Houston, Texas December 1986.

* 20 reprints 1/87

ABSTRACT

In a previous paper, a Fixed Assignment Retransmission ALOHA (FARA) multiple access algorithm was described and analyzed. Under this scheme, collided packets are retransmitted in assigned slots. This ensures that collided packets will not collide with each other again. It was shown that FARA had superior performance when compared with slotted-ALOHA and many other existing contention-biased schemes. However, carrier-sensing was not considered in FARA. In this paper, a Fixed Assignment Retransmission Scheme with Carrier-Sensing Capability (FARCS) is developed. A Markov model is developed to analyze this scheme. The performance of FARCS is shown to be superior to Carrier-Sense Multiple Access with Collision Detection (CSMA/CD). This improvement depends on the maximum propagation delay between a pair of nodes in the network.

****

* Rong-Feng Chang and Victor Li, "Proposed Routing Algorithm for the U.S. Army Mobile Subscriber Equipment (MSE) Network," *Proceedings of MILCOM '86*, Monterey, California, October 1986. 20 reprints 1/87

ABSTRACT

The U.S. Army Mobile Subscriber Equipment (MSE) Network consists of a large number of geographically dispersed, mobile radio terminals which require secure communications. The network is also subject to attacks by the enemy. In this paper, we propose and analyze alternative network routing algorithms for the MSE.

****

* Ting-Chou Hou and Victor Li, "Position Updates and Sensitivity Analysis for Routing Protocols in Multihop Mobile Packet Radio Networks,", submitted for publication in the *IEEE Transactions on Communications*.

* 1 preprint 1/87

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ABSTRACT

A communication network consisting of a large number of geographically dispersed, mobile nodes is considered. Due to the limited transmission power of the nodes, a message must be relayed from node to node before it reaches its destination. Therefore, routing strategies are necessary. Position location and updating are required to support some routing strategies in a multihop mobile Packet Radio Network. Two distributed position update schemes are proposed. Due to updating delays, the position information on some nodes may be inaccurate on network routing protocol performance is studied.

****

* Rong-Feng Chang and Victor O.K. Li, "Delay Analysis of Slotted-ALOHA Multihop Packet Radio Networks," *Proceedings IEEE International Conference on Communications*, Seattle, WA, June, 1987.

* 20 reprints 7/87

ABSTRACT

A delay analysis of multihop packet radio networks is presented. The network has arbitrary topology and each node may serve as a transmitter or a receiver, but not simultaneously. The packet generation processes at the nodes are assumed to be independent Poisson processes. Packets are of fixed length and the transmission strategy used at each node is Slotted ALOHA. One major difficulty in analyzing multihop radio networks is the dependencies of the transmission queues at the various nodes of the network. In this paper, we assume these dependencies are completely characterized by some system parameters. Using an iterative algorithm, we solve these parameters.

****

* Phillip M. Feldman & Victor O.K. Li, "Adaptive Coding for Discrete-Time Markovian Channel", *Proc. of Conference of Data Communication, Systems and Their Performance*, Rio de Janeiro, Brazil, June 1987.

* 20 reprints 12/87

ABSTRACT

This paper analyzes an adaptive communication system which selects one of two block error-correction codes for each packet according to an estimate of the next channel state. The estimator is based on the number of errors in the previous packet; this information is fed back to the transmitter via the acknowledgement. We demonstrate that

such an adaptive system can yield a throughput improvement ratio (TIR) of 1.5 or more under realistic channel conditions. We prove that TIR is bounded from above by 2 and present a set of four conditions under which TIR can approach this bound. An iterative method for computing the exact throughput for any specific set of system parameters is derived and numerical results are given for several sets of codes and channel statistics.

****

* Phillip M. Feldman and Victor O.K. Li, "An Adaptive Hybrid ARQ Protocol for Continuous-Time Markovian Channels," *Proceedings MILCOM '87*, Washington, DC October 1987.

* 20 reprints 12/87

A B S T R A C T

This paper analyzes the throughput of an adaptive hybrid ARQ communications protocol used with a continuous-time two-state Markovian channel. The proposed protocol adapts to changes in the channel state, i.e., changes in noise level, by selecting one of two block error-correction codes for each packet according to an estimate of the next channel state; the estimate, based on the error pattern in the previous packet, is fed back to the transmitter via the acknowledgement. We compare throughputs and computational costs of three next-state estimators. The first, an optimal estimator, is shown to be impractical. A second, suboptimal, estimator is found to require negligible computation and memory. An improved suboptimal estimator is also considered. Throughputs are evaluated; numerical results are presented. The throughput improvement due to adaptation is shown to be greater for the continuous-time channel than for the discrete-time channel with similar parameters. The improvement is also less sensitive to the parameters.

****

* Phillip M. Feldman and Victor O.K. Li, "Delay Analysis for Adaptive Hybrid ARQ Protocol," *Proceedings of MILCOM '87*, Washington, DC, October 1987.

* 20 reprints 12/87

A B S T R A C T

This paper analyzes transmission delays of an adaptive hybrid ARQ communications protocol used with a discrete-time two-state Markovian channel. this channel model allows for both time-varying noise levels and memory. The protocol adapts to changes in channel state, i.e., changes in noise level, by selecting one of two block error-correction codes for each packet according to an estimate of the next channel state; the estimate, based on the error pattern in the previous packet, is fed back to the transmitter via the acknowledgement. Our analysis shows that for some changes of channel state, the adaptive hybrid ARQ protocol can dramatically reduce transmission delays; the regime of channel parameters for which this protocol is useful is thus wider than indicated by

previous analyses of throughput improvement alone. For some channels evaluated, both the mean and standard deviation of the delay were reduced by factors of more than 3 (the reduction in the standard deviation was sometimes more than 4).

****

* Cheng-Shong Wu and Victor O.K. Li, "Receiver-Initiated Busy-Tone Multiple Access in Packet Radio Networks", *Proc. ACM SIGCOMM Symposium on Frontiers in Computer Networking Technology*, Stowe, Vermont, August 1987.

* 20 reprints 12/87

A B S T R A C T

The ALOHA and Carrier Sense Multiple Access (CSMA) protocols have been proposed for packet radio networks (PRN). However, CSMA/CD which gives superior performance and has been successfully applied in local area networks cannot be readily applied in PRN since the locally generated signals will overwhelm a remote transmission, rendering it impossible to tell whether a collision has occurred or not. In addition, CSMA and CSMA/CD suffer from the "hidden node" problem in a multihop PRN. In this paper, we develop the Receiver-Initiated Busy-Tone Multiple Access Protocol to resolve these difficulties. Both fully connected and multihop networks are studied. The busy tone serves as an acknowledgement and prevents conflicting transmissions from other nodes, including "hidden nodes".

****

* Cheng-Shong Wu and Victor O.K. Li, "Random Access for a Multibeam Satellite with Dynamic Transponder Switching," *Proceedings IEEE INFOCOM 88*, New Orleans, LA, March, 1988.

* 20 reprints 12/87

A B S T R A C T

A multibeam satellite communications network servint multiple zones with S-ALOHA random access uplinks and dynamically switched transponders in the downlinks is studied. The overhead of switching transponders between zones may degrade the performance of the system significanly. Two different strategies are introduced and studied. In the Guard Time strategy, each slot time is equal to the packet transmission time plus the transponder switching time, allowing the transponder to be pointed to a new zone at the beginning of each slot. In the Idle Waiting strategy, each slot time is equal to the packet transmission time. If a transponder is switched to a new zone, it will take k slot time, where k is the smallest integer greater than the switching time divided by the slot time. The throughput of these two strategies are analyzed and compared.

****

* Rong-Feng Chang and Victor O.K. Li, "Analysis of Flow Control in Multihop Packet Radio Networks", *Proceedings of the IEEE ICC'88*, Philadelphia, June 1988.

* 20 reprints 6/88

A B S T R A C T

In this paper, we present an analysis of flow control in multihop packet radio networks. The Input Buffer Limit *IBL* network access control scheme, developed in point-to-point computer networks, is adapted to multihop packet radio networks. We show that the delay-throughput performance is improved significantly with flow control, especially under high traffic. We analyze networks with infinite buffer as well as those with finite buffer. The arrival process at each node may be an arbitrary probability distribution. Due to the strong dependencies of the transmission queues at various nodes of the network, an exact analysis is mathematically intractable. Therefore, we have found an approximate solution which can be evaluated using an iterative algorithm.

****

* Victor O.K. Li, "Multiple Access Communications Networks", *IEEE Communications Magazine*, vol. 25, no. 6, pp. 41-48, June 1987.

* 20 reprints 6/88

A B S T R A C T

A communications network consists of a number of terminals that communicate with each other over communications channels. In this article we study those communications networks where multiple terminals share the same channel in their attempt to communicate. This sharing may be necessary because of efficiency considerations, or due to the nature of the application. We call such networks multiple access networks. Due to the sharing, if more than one terminal transmit simultaneously, the reception will be garbled; and if none transmit, the channel will be idle. It is desirable to have multiple access schemes which resolve the conflict among the terminals, such that the channel is used most of the time. Multiple access networks include satellite networks, local area networks, and packet radio networks.

****

* A. Polydoros & K.T. Woo, "Wideband Spectral Detection of Unknown Frequency-Hopping Signals", presented at the *IEEE International Symposium on Information Theory*, Brighton, England, June, 1985. (Abstract only)

ABSTRACT

The problem of detecting weak spread-spectrum signals with unknown parameters in strong noise and/or interference is currently attracting increased interest. Earlier approaches to this problem capitalized on the difference in the energy level between signal-plus-noise hypothesis (H_1) and the noise-only hypothesis (H_0), thereby utilizing an energy-measuring device (radiometer) as the key detection unit. Clearly, such a solution overlooks potentially known features of the sought signal and is, therefore, suboptimal. Using more thorough theoretical tools, the problem has been formulated as a composite (or average) likelihood-ratio (LR) hypothesis test

$$\Lambda \underset{H_0}{\overset{H_1}{\gtrless}} \text{threshold}$$

and optimal solutions have been obtained for the most widely known classes of LPI waveforms, such as Frequency-Hopping (FH), Direct-Sequence (DS) and hybrid spread-spectrum signal sets. Performance of such detectors, employing optimal nonlinearities, has been quantified by means of a "Gaussian: distance (d_G), which is derived on the assumption that the log-likelihood ratio (LLR)ℓ = ρn Λ is Gaussian under hypothesis H_0. Whenever the LR Λ consists of a product of many independent terms, i.e., whenever many code chips (DS) or successive hops (FH) of the sought signal are observed, this is approximately justified via a central-limit theorem argument, since the logarithm turns the product into a large sum of independent terms. In fact, the validity of such a Gaussian distance measure has been recently examined in the DS/LPI detection scenario, and has been recently examined in the DS/LPI detection scenario, and has been found satisfactory for a wide range of values. In this particular signal model, however, quadratic approximations to the optimal nonlinearities perform almost equally well, owing to the fact that typical chip signal-to-noise-ratio (SNR) values are small (much less than one); in other words, for small input-SNR, simple radiometric tests are asymptotically optimal.

Attention in this paper is focused on the FH/LPI wideband detection model. In particular, we assume a very large time-bandwidth product G (> 100). Stated differently, for a single-hop observation interval of T_H sec., the number of candidate hopping frequencies (spectral slots) which the detector must observe (M) is very large. Assuming that the optimal LR test is to be performed, the detector must be provided with a set of M observables, namely the spectral measurements R_m; m=1,...,M at the candidate frequencies. Then the optimal test is of the form

$$\Lambda = (\text{constant}) \sum_{m=1}^{M} I_0\left(\frac{2\sqrt{S}}{N_0} R_m\right) \underset{H_0}{\overset{H_1}{\gtrless}} \text{threshold}$$

when S=signal power, N_0=noise power spectral density (one-sided) and $I_0(.)$=zeroth-order modified Bessell function. Note that such spectral measurements can be implemented via an FFT operation on the sampled input waveform, or by sampling the output of a real-time spectral estimator (e.g. SAWD-chirp filters), or any other spectral estimation algorithm. In terms of qualifying the performance of such an optimal test, two factors must be brought to attention: (a) the hop-SNR = ST_H/N_0 is typically not small, as in the

DS/LPI case; thus, the optimality of the nonlinearity must not be compromised so easily and (b) for single-hop processing, of the kind we are interested herein, it is the Likelihood ratio which is approximately Gaussian, not the log-likelihood ratio. The ramifications from those two factors are:

a. Optimal nonlinearities attain increased importance and

b. the aforementioned LLT-Gaussian distance is useless in this framework.

Instead, distance measures based directly on the LR must be established. The purpose of this talk is to derive such appropriate measures for the optimal composite LR test and evaluate them for a wide range of parameter values of interest. Effects of frequency misalignment will be demonstrated, as manifested both in SNR loss and mismatched scaling. It will be shown how some of that loss can be recovered by optimal and suboptimal algorithms, designed for the worst-case frequency misalignment. Finally, we shall compare this family of optimal or mismatched LR tests with other suboptimal tests, namely (I) the spectral-maximum detector (otherwise known as the hard-decision or the bank of matched filters or simply the periodogram detector) (II) the recently discussed autocorrelation detector and (III) the lower-bounding performance of the radiometer. The robustness of each test to unknown parameters will be discussed, and future direction of research, pertaining to multihop algorithms and corresponding performance will be commented upon.

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* A. Polydoros and C.L. Nikias, "Detection of Unknown-Frequency Sinusoids in Noise, Part I: Spectral Versus Correlation Domain", published June 1987 combined with Part II below, *IEEE Transactions on ASSP*.

* 1 preprint 1/86

A B S T R A C T

The purpose of this two-part paper is threefold: (a) to put into perspective the notions of spectral- versus correlation-domain detection algorithms, (b) to couple such decision rules with certain linear and nonlinear predetection-processing possibilities and (c) to illustrate the concepts by means of numerical examples. The level of computational complexity, parameterized by the problem dimensionality, is discussed in connection with the relative merit (strength) of different algorithms.

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* C.L. Nikias, and A. Polydoros, "Detection of Unknown-Frequency Sinusoids in Noise, Part II: Autoregressive Models," published combined with Part I *IEEE Transactions on ASSP*, June 1987.

* 1 preprint 1/86

A B S T R A C T

The autocorrelation-domain detection concept, formulated in Part I, is further explored here in the framework of autoregressive (AR) modeling. A family of detection schemes is identified from the formulations and their relative merit is examined via comprehensive simulations as a function of the time-bandwidth product, model order, and input SNR. AR models applied to both the time samples and correlation lags are addressed and compared. The computational complexity of the resulting decision rules is given a primary consideration and incorporated in the comparative conclusion.

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* Andreas Polydoros and Chrysostomos L. Nikias, "Advanced Detection of Unknown-Frequency Sinusoids in Broadband Noise," *Proceedings of ICC '86*, Toronto, Ontario, Canada, June 1986.

* 20 reprints 5/86

ABSTRACT

Standard and novel techniques in both the spectral and correlation domains are discussed for the detection of sinusoids with unknown frequency-offset in wideband Gaussian noise. Analytical, simulation and complexity results are provided for comparison purposes.

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* Andreas Polydoros, "On the Wideband Detection of Sinusoids via Parametric Models," presentation at *Northwestern University, Communications and Digital Signal Processing Group Guest Seminar Series*. (Abstract only.)

ABSTRACT

We shall review in this talk various approaches for the detection of an unknown-frequency sinusoid in wideband Gaussian noise, a problem common to radar, spread-spectrum, etc. The classical likelihood-ratio schemes and variants thereof will be evaluated against some promising new parametric alternatives, such as all-pole modeling of the time-domain and correlation domain series. Practical as well as theoretical constraints will receive due attention.

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* Andreas Polydoros and Chrysostomos L. Nikias, "Detection of Unknown-Frequency Sinusoids in Noise: Spectral versus Correlation Domain and

Autoregressive Modeling," *IEEE Transactions on ASSP*, vol. ASSP-35, no. 6, June 1987, pp. 897-900.

* 20 reprints 7/87

ABSTRACT

The purpose of this paper is threefold: (a) to put into perspective the notions of spectral- versus correlation-domain detection algorithms, (b) to couple such decision rules with certain linear and nonlinear predetection-processing possibilities, and (c) to illustrate by simulation results the potential that a family of autoregressive (AR) detection statistics holds for enhanced detection of unknown signals in noise. AR models applied to both the time samples and the correlation lags are addressed and compared. The computational complexity of the resulting decision rules is given a primary consideration and incorporated in the comparative conclusions.

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* Peter R. Pawlowski and Andreas Polydoros, "Adaptive Nonparametric Acquisition of FH-SS Signals in Jamming", *Proceedings of MILCOM '86*, Monterey, CA, October 1986.[1]

* 20 reprints 1/87

ABSTRACT

A matched filter receiver for frequency-hopped spread spectrum code acquisition in jamming is analyzed. The receiver uses an adaptive, nonparametric distribution-free Median Test detector requiring no knowledge or "side-information" about the signal, jammer, and thermal noise parameters to implement an asymptotically constant false alarm rate test. The median of a reference sample set, empirically describing the code-absent probability distribution, determines the threshold used in the nonparametric detector. By updating the reference set every hop epoch, the threshold adapts to the channel condition. Adaptive threshold setting introduces memory so that tests are no longer independent, making exact closed-form analysis difficult. Performance approximations are developed and compared to simulation results illustrating acquisition performance.

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* Andreas Polydoros and Chrysostomos L. Nikias, "On the Detection of

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[1]Acknowledgement of ARO-effort was overlooked in error when this paper was submitted to MILCOM '86.

Unknown-Frequency Sinusoids in Noise: Spectral", presented at the *IEEE Transactions on ASSP Workshop*, Boston, Massachusetts, November 1986.

* 20 reprints 1/87

ABSTRACT

The purpose here is (a) to put into perspective the notions of spectral- versus correlation-domain detection algorithms, (b) to couple such decision rules with certain linear and nonlinear predetection-processing possibilities and (c) to illustrate by simulation results the potential of a family of autoregressive (AR) detection statistics.

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* W.C. Peng, R.A. Scholtz, and L.R. Welch, "Some Link Jamming Games", submitted to the *IEEE Transactions on Information Theory* and to the *1986 International Symposium on Information Theory*, Ann Arbor, Michigan.

* 1 preprint 1/86

ABSTRACT

Link jamming problems are formulated as two-person zero-sum infinite games under the following assumptions: (1) the communicator can randomize its power level and/or data rate, (2) the jammer can randomize its power level, (3) both the communicator and the jammer are subject to average (and peak) power constraints P,J(P_{max},J_{max}) respectively, (4) a threshold model for the success of packet transmissions, (5) throughput as the pay-off function. A memoryless model and a generalized model are presented. The optimal memoryless strategies are proven to remain optimal in the generalized formulation.

Link jamming games with average (and peak) power constraints are then analyzed and saddlepoint throughput values are obtained. When only average power constraints are assumed, it is demonstrated that, from the communicator's point of view, (1) power randomization outperforms rate randomization and (2) power and rate randomization do not result in any improvement over pure power randomization. With peak and average power constraints, the above results remain true when $P_{max} \geq J_{max}$. When $J_{max} > P_{max}$, rate randomization may be helpful.

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* W.C. Peng and R.A. Scholtz, "A Study of Discrete Link Jamming Games," *Proceedings MILCOM '86*, Monterey, CA., October 1987.

* 20 reprints 7/86

ABSTRACT

Link jamming games with continuous levels were studied in [1]. Practically it may not be feasible to implement an optimal power- or rate-randomizing strategy with continuous levels. Games, i.e., design programs, with discrete levels are investigated here. The threshold model and throughput pay-off are the same as in [1]. Average power constraints for both the communicator and the jammer are assumed. Questions like, "If the communicator (jammer) ahas only two power levels for randomization, which two levels are optimal ?" and "What is the maximum signal-to-jamming ratio cost for quantizing the levels ?" will be answered.

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* T.H. Lee and R.A. Scholtz, "Protocol Jamming," *Proceedings MILCOM '86*, Monterey, CA.

A B S T R A C T

Antijamming is one of the most important capabilities of military communication systems. In order to combat jammers even more effectively, the technique of multi-rate communication is inevitably of interest. How to operate a multi-rate system efficiently is, therefore, worthy of study.

This paper presents the feasibility of using a protocol (adaptive or randomized) to govern the process of selecting a rate to transmit in a two-rate system. Two quantities, efficiency and worst case efficiency, are defined as measures of goodness of an adaptive protocol. A particular property, called zero looping, of an adaptive protocol is discussed. One simple method for eliminating zero loops of adaptive protocols is given. Under a certain type of jamming strategy constraint, the average throughput of a randomization protocol as well as the efficiency of an adaptive protocol are computed and compared.

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* Wei-Chung Peng, Robert A. Scholtz and Lloyd R. Welch, "Some Link Jamming Games", presentation at the *1986 IEEE International Symposium on Information Theory*, October 6-9, 1986, Ann Arbor, Michigan. (Abstract only.)

A B S T R A C T

Link jamming problems are fomulated as two-person zero-sum infinite games under the following assumptions: (1) the communicator can randomize its power level and/or data rate, (2) the jammer can randomize its power level, (3) both the communicator and the jammer are subject to average (and peak) power constraints P,J(P_{max}, J_{max}) respectively, (4) a threshold model for the success of packet transmissions, (5) throughput as the pay-off function. A memoryless model and a generalized model are presented. The optimal memoryless strategies are proven to remain optimal in the generalized formulation.

Link jamming games with average (and peak) power constraints are then analyzed

and saddlepoint throughput values are obtained. When only average power constraints are assumed, it is demonstrated that, from the communicator's point of view, (1) power randomization outperforms rate randomization and (2) power and rate randomization do not result in any improvement over pure power randomization. With peak and average power constraints, the above results remain true when $P_{max} \geq J_{max}$. When $J_{max} > P_{max}$, rate randomization may be helpful.

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* Tsern-Huei Lee and Robert A. Scholtz, "Protocol Jamming", *Proceedings of MILCOM '86*, Monterey, CA., October 1986.

* 20 reprints 7/86

ABSTRACT

Antijamming is one of the most important capabilities of military communication systems. In order to combat jammers even more effectively, multi-rate communication techniques are sometimes used.

This paper explores the feasibility of using a protocol (adaptive or randomized) to govern the process of selecting a rate to transmit in a two-rate system. Two quantities, efficiency and worst case efficiency, are defined as measures of goodness of ar adaptive protocol. A particular property, called zero looping, of an adaptive protocol is discussed. One simple method for eliminating zero loops of adaptive protocols is given. Under a certain type of jamming strategy constraint, the average throughput of a randomized protocol as well as the efficiency of an adaptive protocol are computed and compared.

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* Duncan M. Dlugos and Robert A. Scholtz, "Acquisition of Spread Spectrum Signals by an Adaptive Array," *Proceedings of MILCOM '86*, Monterey, CA., October 1986.

* 20 reprints 7/86

ABSTRACT

This paper discusses discrete-time processing techniques for the acquisition of a direct-sequence-spread-spectrum signal from an antenna array. Both constant data and random data modulating the code are considered. The maximum likelihood procedures for estimating the received code lag are described, assuming an unknown channel and interference of either known or unknown covariance. Analytic and simulation results for performance of the optimum processors, as well as suboptimum procedures, are presented.

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* Samir S. Soliman and Robert A. Scholtz, "Synchronization over Fading Dispersive Channels", *IEEE Transactions on Communications*, vol. 36, no. 4, pp. 499-505, April 1988.

* 20 reprints 6/88

ABSTRACT

This paper investigates the performance of an initial synchronization system, for digital communication over fading dispersive channels, which is optimum in the sense that it achieves synchronization with a given probability in the minimum possible time. A performance measure for the synchronizer in the acquisition mode is defined. Upper and lower bounds on the performance measure are derived. The effect of various parameters, such as signal-to-noise ratio, pulse width and modulation, number of pulses, spread of the channel, and the size of the resolution cell on the performance of the synchronizer are investigated.

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* Samir S. Soliman and Robert Scholtz, "A Technique to Approximate the Eigenvalues of Autocorrelation Functions," submitted to the *IEEE Transactions on Communications*.

* 1 preprint 1/87

ABSTRACT

This paper proposes a probabilistic model for the eigenvalues and investigates the use of the theory of moments to obtain an approximation to the eigenvalues of a homogeneous Fredholm integral equation of the second kind of Hermitian kernel.

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* T.H. Lee, W.C. Peng, and R.A. Scholtz, "Power and Rate Selection for Structured Jamming Games," submitted for publication.

* 1 preprint 7/87

ABSTRACT

Optimal strategies as well as saddle-point throughputs of several highly structured jamming games are presented in this paper. A threshold model is used as a criterion to determine whether a transmitted packet will be successfully received by the receiver. The cost of limiting the data rate and power level sets to a finite size, as compared to having available a continuum of rates and power levels is evaluated. Also presented in this paper is an evaluation of the robustness of a system design based on a nominal value of opponent's parameter.

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* Samir S. Soliman and Robert A. Scholtz, "Spread Ambiguity Functions," *IEEE Transactions on Information Theory*,, vol. 34, no. 2, pp. 343-347, March 1988.

* 20 reprints 6/88

ABSTRACT

A generalized spread ambiguity function is defined and its relationship to the Woodward's ambiguity function for different models of targets is developed. The properties of the spread ambiguity function are derived.

It has been shown that smoothing the autocorrelation function of the signal part of the received waveform by the scattering function of the channel does not alter the properties of the ambiguity function. Measures of rms correlation time and rms correlation bandwidth for non-stationary processes are defined. Finally, an example is given to demonstrate how spread ambiguity functions can be used to help in signal design when dealing with doubly spread targets.

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* Robert A. Scholtz, "A Survey of Aperiodic Sequence Designs for Communications", *Proceedings of the International Symposium on Information and Coding Theory*, Campinas, Brazil, July 27-Aug. 1, 1987.

* 20 reprints 12/87

ABSTRACT

The use of correlators for many purposes in communication and radar systems motivates the design of waveforms with good correlation properties. Digital waveforms for these systems, consisting of sequences appropriately modulated onto carriers, must have certain correlation properties to insure proper system performance. For single sequences, these constrains usually are the result of time-of-arrival or time resolution requirements, while constraints on cross-correlation between sequences are usually motivated by the

ability to distinguish waveforms (and hence determine the information that they bear) in a noisy environment.

In this paper we will survey some of the different kinds of aperiodic correlation constraints that have been placed on sequence designs by various operating conditions, reference some classic work, and discuss recent results and open problems. Sequence designs to be reviewed include (a) Barker sequences, the Huffman and Golay design concepts, two-dimensional Barker arrays (their relation to one-dimensional problems, existence conjectures), and (b) sonar sequences, Costas arrays, Golomb rulers and rectangles, PPM sequences (definitions of and relationships between these designs, sample designs for single and multiple sequences, new results and conjectures).

One byproduct of this survey is the illustration of the taxonomy of sequence and array designs. It is the author's desire that this paper will make these sequence designs more accessible to the practicing design engineer, and interest the mathematically inclined reader in challenging and potentially useful areas of research.

This paper surveys a variety of research results achieved under several research contracts, including some from the previous Army Research Office.

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* Sabah Alquaddoomi and Robert Scholtz, "On the Nonexistence of Barker Arrays and Related Matters", submitted to the *IEEE Transactions on Information Theory*.

* 1 preprint 6/86

A B S T R A C T

Evidence is presented to support the conclusion that there exists only one equivalence class of binary two-dmensional arrays of +1's and -1's with all out-of-phase aperiodic autocorrelation values bounded in magnitude by unity. The representative of this class is the 2×2 array

$$\begin{vmatrix} 1 & 1 \\ 1 & -1 \end{vmatrix}$$

The results of a computer search for binary arrays which have the smallest maximum out-of-phase autocorrelation magnitude are presented. It is proven that no binary array with correlation sidelobe magnitudes bounded by unity exists when either dimension is an odd prime, or when one dimension is an odd integer and the other is twice an odd integer.

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* Duncan M. Dlugos and Robert Scholtz, "Acquisition of Spread Spectrum Signals by an Adaptive Array", submitted to the *IEEE Transactions on Acoustics, Speech and Signal Processing.*

* 1 preprint 6/88

A B S T R A C T

This paper descusses discrete-time processing techniques for the acquisition of a direct-sequence-spread-spectrum signal from an antenna array. Both constant data and random data modulating the code are considered. The maximum likelihood (ML) and least squares procedures for estimating the received code lag are described, assuming an unknown channel and interference of either known or unknown covariance. Analytic and simulation results for performance of the optimum estimator are presented. The ML procedure for data estimation is also described.

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* Charles, Weber, "Acquisition in Wideband Communication Systems," Presentation at the *Electrical Engineering Colloquium at the Ohio State University*, Columbus, Ohio, May 9, 1986. (Abstract only.)

A B S T R A C T

The process of acquisition will be described for both direct sequence and frequency hopping systems. The models and analytical tools necessary for developing a unified approach to estimating the performance of acquisition algorithms will be developed. Finally, some comments will be given about problems with the acquisition process in the presence of interference.

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* Min In Chung and Lloyd R. Welch, "3-D Bit Serial VLSI Architectures with Minimum Propagation Delay. Examples: Reed-Solomon Code Encoder and Decoder," submitted to *IEEE Transactions on Computers.* (This paper is currently being reviewed.)

* 1 preprint 5/86

A B S T R A C T

This paper presents 3-dimensional bit-serial architectures for the Reed-Solomon code encoder and decoder (error locator part) which can achieve minimum propagation delays in VLSI. The architecture is based on the generalized transversal filter network structure and the interpretation of the continued fraction algorithm as a shift register

synthesis process. Another new transversal filter structure called double transversal filter is also defined. It is shown that the continued fraction algorithm can be interpreted as the joint operations of three double transversal filters. The natural correspondence between the continued fraction algorithm's recursion formula and the synthesized shift registers is studied. The presented result not only provides further insight into the error correcting code decoding process but also exemplifies a new approach for VLSI design.

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* Kuo-Hui Liu and Lloyd R. Welch, "Delta Sequences and the Counting of Local Orthogonal Sequences," submitted to the *IEEE Transactions on Information Theory*. (This paper is currently under review.)

* 1 preprint 12/87

A B S T R A C T

Local orthogonal sequences are sequences with periodic autocorrelation R(t) = 0 for $1 \leq |t| \leq$ TMAX, where TMAX is some fixed integer. Delta sequences $\{a_i\}$ is the sequence generated by bitwise sum of a {0,1} sequence $\{b_i\}$ and its single cyclic shift, i.e. $a_i = b_i + b_{i+1}$, where summation is mod 2. First, we will study some properties of delta sequences. Then we apply these properties to get the if and only if conditions for the delta sequences of local orthogonal sequences up to TMAX = 4. The close form formula of the number of cyclic distinct local orthogonal sequences for TMAX less or equal to 3 are also derived.

Ph.D. Theses

* **John Gilbert Robbins**, "Joint Decoding of Interleaved RS Codes and a Correlation Concept for a Class of Sequences", Ph.D. Dissertation, Department of Electrical Engineering, University of Southern California, Los Angeles, August 1985.

* 1 copy enclosed 1/86

A B S T R A C T

I. The term joint decoding is used to describe simultaneous decoding of a set of interleaved codes each with the same set of error locations caused by burst errors. This permits decoding beyond the designed error correcting capability of the component codes at a cost of a nonzero probability of decoding failure. Two algorithms, Gaussian elimination and a Hankel matrix algorithm due to J. Rissanen, are described in which joint decoding is accomplished by combining the syndrome information into one system of linear equations which is solved to give the error locator polynomial. The continued fraction form of Berlekamp's algorithm is adapted to joint decoding by computing the error locator polynomial for each component code as fully as known syndromes permit and using the fact that they all have the same set of roots to combine the information on the polynomials to construct a system of linear equations which is solved to give polynomials used to compute the error locator polynomials.

Joint decoding of codes over GF(q) interleaved to depth c with 2t check symbols per code permits computing 2ct/(c+1) error locations with a probability of decoding failure of approximately 1/q. The probability of decoding failure can be reduced by providing one or more additional check symbols for one or more codes. Simulation results are given for each of the algorithms, demonstrating the effect of additional check symbols.

II. The function $N_\tau(a,b) = |\{x \mid F(x) = a, F(x+\tau) = b\}|$ is proposed as a convenient measure of correlation performance of frequency hopping sequences over prime power fields. The function is applied to sequences of the form $F(\alpha^i)$, defined by a function F mapping $GF(q^{2k})$ onto GF(q). For the function $F(\underline{X},\underline{Y}) = \underline{X}^t\underline{Y}$, in which $\underline{X}$ and $\underline{Y}$ are k-tuples over GF(q), formulae are derived which permit cataloging the values taken by N(a,b). In particular, the largest value of N(a,b) normalized by the length of the sequence for $\tau \neq 0$ is $q^{-1} + q^{-k}$.

The function F was selected because, as a mapping of $GF(2^{2k})$ onto GF(2), it is a bent function and has good linear span. The second function, $F(x) = Tr_1^k(Tr_k^{2k}(x)Tr_k^{2k}(x\beta))$ is inspired by both the bent functions and GMW sequences. Partial results are obtained for N(a,b) for this function.

John Robbins was supported under Contract DAAG29-79-C-0054, and Dr. L.R. Welch's efforts on behalf of this thesis were supported in part by ARO.

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* **Robert M. Ward Jr.**, "Optimization of Full-Time and Time-Shared Noncoherent

Code Tracking Loops," Ph.D. Dissertation, Department of Electrical Engineering, University of Southern California, Los Angeles, August, 1985.

* 1 copy enclosed 1/86

A B S T R A C T

Four noncoherent correlative code tracking loops are presented. The tracking performance and acquisition behavior of each loop is analyzed. The results include the standard noncoherent delay-lock-loop, the time shared version of that loop known as the tau-dither-loop, and modified versions of each. The ensuing numerical results can be used to indicate how the loop structures can be optimized in accordance with performance criteria mentioned below.

From the stochastic differential equation, the generalized S-curve and the autocorrelation of the equivalent noise at the input of the loop filter are derived for each loop. Subsequently, the power spectral density is computed. Intensity coefficients are determined as the inputs to the renewal equations, whose solutions lead to the probability density function of the tracking error process. The latter step allows for calculation of the variance of the tracking error and the mean time to lose lock. Previous linear and nonlinear results are shown to be special cases of the work herein.

The acquisition behavior of the four loops in the absence of noise is characterized using standard phase plane trajectory analysis techniques. Results compare the ability of the standard and modified loop versions to acquire and track signals with constant doppler velocity. Key parameterizations include the loop damping factor and code chip offset.

A. Polydoros and C.L. Weber's efforts on behalf of this thesis research, were supported in part by ARO.

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* **Roy Daron Cideciyan**, "Network Synchronization Techniques in the Presence of Oscillator Drift and Time-Varying Delay", Ph.D. Dissertation, Department of Electrical Engineering University of Southern California, Los Angeles, CA, December 1985.

* 1 copy 7/86

A B S T R A C T

The study of network synchronization techniques in the presence of time-varying transmission delay and long term clock instability is virtually absent from the literature. In this thesis the effects of clock drift and time-varying delay on master-slave and mutually synchronized systems are analyzed and the synchronization performances of twelve

different network topologies of practical interest are compared to each other.

Using the sinusoidally and linearly varying channel delay models, nodal frequency differences and their upper bounds are calculated for two-nodal one-way and two-way master-slave systems. For both transmission delay models the performance of the two-way master-slave synchronization technique is far superior to the performance of the one-way master-slave synchronization technique.

A unified approach to the investigation of long term clock instability effects in n-nodal mutually synchronized and master-slave systems is presented and sufficient stability conditions for both systems are derived. The general formulas for the system frequency drift rate and nodal frequency differences of n-nodal mutually synchronized and master slave systems are obtained. To compare different configurations of mutually synchronized and master-slave systems, the variance of the nodal frequency difference is introduced as a performance measure.

An important result pertaining to mutual synchronization is that for networks with high symmetry the system frequency drift rate is the average of the free running clock drifts. Consequently, the rms value of the fractional frequency deviation in mutually synchronized clocks decreases with $1/\sqrt{N}$ where N is the total number of clocks in the network. the increase in long term stability can be attained with very low connectivity as in the case of the single loop configuration.

Among the four different mutual synchronization configurations investigated, the fully connected and the single loop configurations exhibit the lowest variances of the nodal frequency differences. The master-slave star system, which consists of independent two-nodal two-way master-slave systems sharing a common master clock, has the best performance among the eight different master-slave configurations investigated. In fact, the master-slave star topology outperforms all the topologies discussed in this thesis.

Roy Cideciyan was supported on contract DAAG29-82-K-0142.

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* **Wei-Chung Peng**, "Some Communication Jamming Games," Ph.D. Thesis, Department of Electrical Engineering, University of Southern California, Los Angeles, CA, January 1986.

* 1 copy enclosed 7/86

ABSTRACT

Link jamming problems with continuous power (and rate) levels are formulated as two-person zero-sum infinite games under the following assumptions: (1) the communicator can randomize its power level and/or data rate, (2) the jammer can randomize its power level, (3) both the communicator and the jammer are subject to average (and peak) power constraints P,J (P_{max},J_{max}) respectively, (4) a threshold model for the success of packet transmissions, (5) throughput as the pay-off function. A memoryless model and a generalized model are presented. the optimal memoryless

strategies are proven to remain optimal in the generalized formulation.

Link jamming games with average (and peak) power constraints are analyzed and saddlepoint throughput values are obtained. When only average power constraints are assumed, it is demonstrated that, from the communicator's point of view, (1) power randomization outperforms rate randomization and (2) power and rate randomization do not result in any improvement over pure power randomization. With peak and average power constraints, the above results remain true when $P_{max} \geq J_{max}$. When $J_{max} > P_{max}$, rate randomization may be helpful.

Discrete-level link jamming games are studied next. It is assumed that when the communicator (jammer) discretizes its levels first, it must design for the worst jammer (communicator) which has the level information available. With only average power constraints, the throughput of games with discrete power (rate) levels are obtained. Compared to the throughput results in continuous games, a quantization loss of a few db in P/J is commonly found for the side which first chooses its two optimal power (rate) levels. ?1;2c The effect of distance uncertainties is then studied under a simple model. with the optimal forward progress as the performance criterion, the P/J cost for the jammer's not knowing the position of the receiver is found to be 3-5 db, and it could be 6-10 db if the jammer does not randomize its power. A network model used in [32] is reviewed and a jammers' program is presented. For poisson-distributed independent jammers in a plane, not randomizing the jamming power is found to be the optimal jamming strategy for the jammers when creating more interference power at the receiver is the goal of jamming.

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* **Elvino Silvera Sousa**, "On Distributed Spread Spectrum Packet Radio Networks," Ph.D. Dissertation, Department of Electrical Engineering University of Southern California, Los Angeles, CA, November 1985.

* 1 copy 7/86

ABSTRACT

In this thesis we study various aspects of spread spectrum packet radio networks. The second chapter deals with throughput per unit bandwidth bounds for a system with a large number of users simultaneously transmitting. In chapter 3 we propose 2 spreading code protocols and give throughput results for a single-hop system. The spreading code protocols are the terminal's protocols for choice of transmitting code and, when the terminal is idle, the monitoring code. With spread spectrum signaling, since multiple simultaneous successful transmissions are possible, the throughput is not only dependent on the channel but also on the tendency of the terminals to pair-up as transmitter-receiver pairs. For a system of large processing gain we give the limiting throughputs, which correspond to utilizations, of .343 and .398 for unslotted and slotted systems respectively with a large number of users. Finally chapters 4 and 5 deal with multi-hop networks. In chapter 4 we derive the probability density of the interference power at a

given point of a large random network and find optimum transmission ranges. The probability laws of of the interference power are the stable laws; in particular for a signal which attenuates as an inverse fourth power the probability law is the stable law of exponent 1/2, the density is known as the inverse Gaussian density. The optimum transmission ranges are proportional to a fractional power of the processing gain. In chapter 5 we draw some random networks using a graphics program and observe network connectivities as some of the network parameters are varied.

J. Silvester's efforts on behalf of this thesis research, were supported in part by ARO. Elvino Sousa was supported under a previous Army Contract.

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* **Szu-Lin Su**, "Performance Analysis of Spread Spectrum Networks," Ph.D. Dissertation, Department of Electrical Engineering University of Southern California, Los Angeles, CA, December 1985.

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ABSTRACT

This thesis develops performance models of multihop spread spectrum networks. These networks are designed to combat jamming, multiuser interference, and multipath effects. In addition, they allow for secure communications and low probability of intercept.

A basic equation to calculate the probability of a successful transmission in a slotted-ALOHA spread spectrum network is obtained. This equation accounts for the effects of capture, jamming, and multiuser interference. An iterative procedure is developed to analyze the throughput/delay performance of multihop packet radio networks with buffered nodes. This procedure is applied to the slotted ALOHA network and the slotted spread spectrum network under different transmission protocols. Three active acknowledgement protocols have also been proposed and analyzed. It is shown that that the approximate analytic results match the simulation results very closely.

An efficient distributed synchronization algorithm is developed for a plesiochronous network of mobile, geographically dispersed radio nodes which use spread spectrum signals to communicate with each other. This proposed scheme includes the measurement of the distances between any pair of adjacent nodes. Finally, a model is presented to calculate the end-to-end throughput of unslotted spread spectrum networks.

Victor Li's efforts on behalf on this thesis research, were supported in part by ARO.

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* **Thomas J. Kolze**, "A New Class of Algorithms for Soft Decision Decoding of Linear Block Codes, " Ph.D. Dissertation, Department of Electrical Engineering University of Southern California, Los Angeles, CA, December 1985.

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ABSTRACT

A class of algorithms for decoding binary linear block codes using soft decisions is presented. The performance of the various algorithms applied to the Golay (23,12) code is characterized through the use of simulations and upper-bounds. Within the class of algorithms, the performance runs from near hard decision performance to near optimum, unquantized soft decision decoding techniques, using the Golay (23,12) code, indicates that the new class of algorithms may contain the least complex of the available approaches, depending on the performances required.

The new class of algorithms falls into the category of "list of candidate codewords" soft decision decoding techniques described by Forney [9,16]. As such, some similarity with other approaches is evident [12,14,16,35], while key differences exist which may ease implementation. In the "list" approach, a *truncated* list of candidate code-words is generated after every received data block, rather than using the entire set of 2^k codewords. Then one of the candidate codewords is selected as the estimate of the transmitted codeword, based on correlation or distance calculations with the received signal.

A feedback technique is also presented wherein additional candidate code words are created from comparison between existing candidate codewords and the received hard decision data. This technique also is applicable to other "list of candidate codewords" decoding techniques. The additional improvement in performance provided by the feedback approach is determined for the new class of algorithms and for a previously known technique, the Chase Algorithm 3.

Perhaps the two best features of the new class of algorithms are its versatility, and the wide range of complexity and performance available within the class. In any case, the new class of algorithms provides communication systems engineers with a variety of new and attractive performance versus complexity tradeoffs.

C.L. Weber's efforts on behalf of this thesis research, were supported in part by ARO.

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* **Chen-Yan Lai**, "The Uses of Projective Plane over GF(3) for Constructing Good Codes and Combinatorial Designs," Ph.D. Dissertation, Department of Electrical Engineering University of Southern California, Los Angeles, CA, January, 1986.

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ABSTRACT

In this thesis, a new method to treat projective plane over GF(3) for constructing good codes and combinatorial designs has been developed. Based on the permutation equivalences of codes and combinatorial designs, the method has been shown to be effective and useful.

Two important 2-transitive symmetric designs, (13,4,1)- and the unique (11,5,2)-configurations, are constructable by this method. Some good codes, such as Hadamard codes, and various Golay codes, as well as optimal (9,20,4) codes have also been constructed using this method.

L.R. Welch's efforts on behalf on this thesis research, were supported in part by ARO.

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* **Duncan Dlugos** "Acquisition of Spread Spectrum Signals by an Adaptive Array," Department of Electrical Engineering, University of Southern California, Los Angeles, CA, March 1986.

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ABSTRACT

This work investigates the acquisition of direct-sequence-spread-spectrum-signals (DS-SS) by an adaptive antenna array in the presence of stationary Gaussian interference, by employing multidimensional maximum likelihood estimation. The objective of the estimator is to determine the code offset of the signal at the receiver. The DS-SS code and the location of possible data transitions with respect to the code are known to the receiver.

A sampled data approach to the multidimensional acquisition problem is considered, in which the array is not assumed to have had a chance to adapt before acquiring, and the acquisition decision is made using just one K-sample block of data. Thus, array adaptation and code acquisition take place simultaneously.

Maximum likelihood (ML) code offset estimators assuming a general, unknown, dispersive, multidimensional channel are derived for not data modulation and random data modulation of the code. Both the ML known covariance (ML-KC) and ML unknown covariance (ML-UC) estimation procedures are considered. The LS procedure for an arbitrary length channel is also derived. Performance assuming uncorrelated-in-time interference is derived analytically, and verified by Monte Carlo simulation. Performance is specified as probability of error P_E in choosing the code delay from the K possible delays, as a function of generalized array SNR (GSNR), which is a scalar. Dependence of the GSNR on various parameters is also investigated.

As the code length K increases, the performance difference between the ML-KC and ML-UC estimators decreases. The ML-UC data present estimator sacrifices approximately 1.5 dB in performance compared to the no-data ML-UC performance.

In a multivariate statistics sense, the ML-UC acquisition procedure can be viewed as the classification of a set of vector observations X that are characterized by the multivariate general linear model $\bar{X} = CP_{\ell_0}$, where the channel C, the covariance R and the code lag ℓ_0 are unknown and to be estimated.

The performance of the ML-UC binary hypothesis test, applicable to detection, is also analytically derived.

R.A. Scholtz's efforts on behalf on this thesis research, were supported in part by ARO.

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* **Christopher John Miller**, "Multiple Radio Source Location Using an Array of Moving Passive Sensors," Ph.D. Dissertation, Department of Electrical Engineering University of Southern California, Los Angeles, CA, May 1986.

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ABSTRACT

In this investigation, a new algorithm is derived for the maximum likelihood estimation of the locations of multiple radio sources from signals received by multiple independently moving passive receivers. The individual source signals themselves are considered complete unknowns to the received system and are estimated for an hypothesized spatial arrangement of the sources (i.e., a set of source locations). The degree of success of the estimated source signals to account for the observed waveforms (as measured by a sum of squares residual) is used to judge the source locations hypothesis. The most successful hypothesis is the maximum likelihood estimate of the locations of the sources.

The special characteristics of the source location problem considered here are that there are multiple source signals and that the sensors move independently producing significant differential doppler. The combination of these two factors puts the problem outside the scope of previous algorithms.

The algorithm derived here may be applied whenever it is desired to passively survey the locations of radio transmitters using the signals observed by multiple moving receivers. The types of sources to be located are typically noncooperative, either by choice, unwittingly, or unable to cooperate and may be any type of radio source such as communications transmitters, radars, beacons, jammers, or astronomical sources. In addition the sources may include reflections from unknown directions of sources with otherwise known locations. The algorithm in its present form pertains only to radio sources because a narrow band doppler assumption is applied in which all the source signal spectral components experience the same doppler shift as the RF center frequency. With a more elaborate propagation model, the algorithm could be expanded in principle to handle sonar situations where the narrowband doppler assumption is violated.

Although doppler shifts are explicitly handled by the algorithm, doppler due to source motion is not. A moving source would most likely confuse the algorithm to the extent that no source location hypothesis would have sufficient success in accounting for

the observed waveforms (without overstating the number of source signals present). Again in principle the algorithm could be expanded to handle source velocity and heading as additional free variables to be estimated, however the amount of work expended by the algorithm is exponential in the number of free variables.

R.A. Scholtz's efforts on behalf on this thesis research, were supported in part by ARO.

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* **Yuen Fung Lam**, "Reliability Modeling and Analysis of Communication Networks with Dependent Failures," Ph.D. Dissertation, Department of Electrical Engineering University of Southern California, Los Angeles, CA, May 1986.

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A B S T R A C T

Reliability is one of the most important performance measures of communication networks, and this subject has been studied extensively. However, the problem of statistical dependencies between component failures has received very little attention, while the traditional assumption that network components fail independently is obviously unrealistic. In this dissertation, the problem of statistical dependencies between component failures in the reliability analysis of communication networks is considered. Two inherent difficulties with the conventional use of conditional probabilities to model failure dependencies are identified, and a new Event-Based Reliability Model is presented as an alternate approach. Advantages of this new modeling technique over the use of conditional probabilities are discussed. For reliability calculations, the applicability of existing algorithms and techniques to the new model are examined. Particular attention is focused on a recent technique which bounds network reliability by enumerating and analyzing the most probable states of a network, and a more flexible and efficient algorithm is given. The enumeration technique can also be used to solve a large class of combinatorial optimization problems and design problems, and two modified versions of the enumeration algorithm are developed for achieving better efficiency in certain situations.

Victor Li's efforts on behalf on this thesis research, were supported in part by ARO.

* **Kevin Merrill Buckley**, "A source Representation Space Approach to Digital Array Processing", Ph.D. Dissertation, Department of Electrical Engineering University of Southern California, Los Angeles, CA, July 1986.

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ABSTRACT

This dissertation describes the development and application of a model for sources, as observed by a sensor array processing structure, which accounts for variation in source propagation and observation parameters.

The source observation is a KL-dimensional vector which contains L delayed samples of the output of the elements of a generally configured array of K sensors. The model, termed a Source Representation Space, is an efficient 2nd order characterization of source observations. It is the subspace of the KL-dimensional observation vector space which, for a selected dimension and range of source parameter variation, contains the maximum observed source energy of any equal dimension subspace. It is defined as the span of the significant eigenvectors of a properly constructed Hermitian source sample covariance matrix. The model is generally formulated to represent sources over ranges of propagation and observation parameters. The principle application addressed in this dissertation is the representation of sources over ranges of location and frequency.

The source representation space is used as a source model for spatial/spectral filtering. For this application, where beamformer response is naturally considered in terms of 2nd order characteristics, this representation is employed very effectively. The new representation is used in the control of portions of the response of a broadband linearly-constrained minimum variance beamformer. A class of eigenvector constraints are derived which, compared to existing response point and derivative constraints, is illustrated to provide better response control. Also, a deterministic beamformer design procedure is formulated based on the developed eivenvector constraints. With the procedure, beamformers for broadband and arbitrarily configured arrays can be effectively designed. To date, a general design procedure for broadband and arbitrarily configured array beamformers has not been presented.

For application to broadband Source Location Estimation (SLE), several new broadband spatial spectra estimation algorithms are developed. For power spatial spectra estimation, deterministic and minimum variance beamformers are employed which are designed using eigenvector linear constraints. For eigenvector based high resolution methods, the source representation space is used: 1) to provide valuable insight for algorithm development; 2) as a model of sources for direct broadband data processing algorithms; and 3) to derive transformations which provide source focusing.

Lloyd Griffiths' efforts on behalf of this thesis research, were supported in part by ARO.

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* **Peter Wayne Kinman**, "Laser Doppler and Range Measurements with Active Transponders", Ph.D. Thesis, Department of Electrical Engineering, University of Southern California, Los Angeles, CA, November 1986.

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ABSTRACT

This dissertation describes and analyzes two types of systems for performing doppler and range measurements with active transponders employing lasers. The first such system uses direct-detection optical receivers and hence, is a noncoherent optical system. The other type of system considered is one that uses heterodyne optical receivers -- a coherent optical system. These two optical systems are analyzed with the primary objective of finding the measurement errors for doppler and range, leading eventually to comparisons of the relative advantages of the systems. Since these two types of optical systems inherit architectural features from existing microwave doppler and range measurement systems, this chapter begins with a review of the latter.

Robert Gagliardi's efforts on behalf of this thesis research, were supported in part by ARO.

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* **George Stephen Mecherle**, "Maximized Data Rate Capability for Optical Communication Using Semiconductor Devices with Pulse Position Modulation" Ph.D. Dissertation, Department of Electrical Engineering University of Southern California, Los Angeles, CA, May 1986.

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ABSTRACT

Optical communication systems which incorporate a laser diode transmitter and an avalanche photodiode (APD) receiver have many practical advantages due to all-semiconductor ontoelectronics. A model is developed for an APD receiver, which is shown to have dominant noise contributions from signal-dependent excess noise and preamplifier thermal noise at high data rates (HDR). For a receiver using pulse position modulation (PPM), the data rate can be written $R_D = \alpha\rho_a$, where α is the modulation and coding efficiency in bits/photon and ρ_a is the average photon rate (photon/sec.). It is shown that for the HDR APD receiver with an average-power limited source the data rate capability is optimized by maximizing the coding efficiency α, but for a peak-power limited source both α and ρ_a influence the data rate capability. The optimum choice of PPM word size (M) is then dependent on the source peak-to-average power ratio, which may supersede bandwidth or computational constraints.

The influence of detection schemes and error correcting codes on data rate capability is examined. The detection alternatives for unencoded PPM include the M-ary maximum count and threshold strategies, as well as a binary detection version of maximum count. M-ary maximum count offers the best performance as it is a maximum-a-posteriori (MAP) strategy. When error correcting codes are employed the decoder has the additional option for soft decisioning, which can be exploited by algebraic codes that can correct twice as many erasures as errors. Encoded detection alternatives include the threshold and Δ-Max M-ary soft decision strategy, and a (hard or soft) binary decision

strategy. Δ-Max offers slightly better performance than the other schemes by optimizing the relative number of errors and erasures, although it is not a true MAP strategy. A method of coding for M^Y blocks integer numbers of PPM words together to form a new symbol for the error correcting code. This frees the PPM modulator to use a different set of M-ary symbols, so that the PPM word size and code parameters may be optimized independently.

Multiple laser diode sources can be combined to increase the overall system data rate capability. Optical systems for combining laser diodes are shown to increase the number of photons collected by a distant receiver only for combining by wavelength and/or polarization. Optical elements for combining such as multilayer interference filters, diffraction gratings, and thin metal film polarizers are compared for spectral and polarizing performance as well as implementational requirements. Optical systems for combining include the polarizer/dichroic, bandpass filter, diffraction grating, and broadband polarizing combiners. Combining systems are shown to require a generalized concept of Strehl ratio, which includes the effect of relative source misalignment in addition to combining-related wavefront errors and angular dispersion.

An optical combiner may be incorporated into a communication system using the options of power combining, parallel channels, or matrix modulation. Although each scheme can ideally achieve a factor of N improvement in data rate capability with N diodes combined, power combining is susceptible to background radiation and matrix modulation may be limited by the source peak-to-average power ratio. Parallel channels does not have these limitations but requires the most hardware to implement. It is concluded that power combining with an etalon background filter is the best tradeoff of performance and complexity for systems which are not limited by background radiation or component bandwidth.

Robert Gagliardi's efforts on behalf of this thesis research, were supported in part by ARO.

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* **Peter Pawlowski**, "On the Acquisition of Frequency-Hopped Spread Spectrum Signals in Jamming", Ph.D. Dissertation, Department of Electrical Engineering University of Southern California, Los Angeles, CA, May 1986.

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ABSTRACT

Spread Spectral Modulation is a digital data transmission technique whose characteristics Scholtz [35] has defined as follows: "Spread spectrum is a means of transmission in which the signal occupies a bandwidth in excess of the minimum necessary to send the information; the band spread is accomplished by means of a code which is independent of the data, and a synchronized reception with the code at the receiver is used for despreading and subsequent data recovery." The code described in the previous definition is some known, periodic, pseudorandom (or pseudonoise, "PN")

symbol sequence which is used to modify the transmitted data sequence. In a Direct Sequence (DS) spread spectrum system, the code generally has a rate much larger than the data symbol rate. The code multiplies the data sequence directly, as shown in Fig. 1.1. By the convolution theorem, bandwidth spreading is accomplished through the convolution of the data sequence spectrum with the PN code sequence spectrum. In a Frequency-Hopped (FH) system, the PN code is used to generate a pseudorandom sequence of carrier frequencies. This sequence is mixed with the data signal which may be either at baseband or some IF frequency, as shown in Fig. 1.2. The bandwidth spreading is accomplished by designing the pseudorandom carrier sequence to agree apriori upon the spreading sequence used. However, direct knowledge of the received code phase is generally not available at the receiver. Therefore, the receiver must perform a synchronization process whereby the phase of the received code sequence is estimated (Acquisition) and this phase synchronization is maintained (Tracking). Acquisition is the process where a local code replica stored within the receiver is brought into coarse alignment with the received PN code, where coarse alignment means within one code symbol or hop duration.

Andreas Polydoros' efforts on behalf on this thesis research, were supported in part by ARO.

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* **Mohsen Sarraf**, "Multiple Access Radio Networks: Design and Analysis," Ph.D. Dissertation, Department of Electrical Engineering University of Southern California, Los Angeles, CA, July 1986.

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A B S T R A C T

Information has always been one of the most important and the most valuable commodities in the world. Since the beginning of history man has been trying to convey, store and process information in a reliable, expedient and economical manner. As time passes and technology evolves, not only does the amount of information needed to be stored, processed, or conveyed increase, but also faster and more reliable communication of this information is required.

In the past several decades, the invention of digital computers, as well as achievements in digital and analog communications have revolutionized the information industry. Advances in electronics and communications made transfer of information faster, more secure, and less expensive; while computers were found to be much faster, less wasteful of space, and more economical for information processing and storage. As the use of computers became more widespread, sharing of their resources and/or stored data became important.

These are some of the most important, but by no means the only reasons why so much attention has been focused on computer networking in the recent decade. Ever since computers have been found to be more helpful and more powerful as elements in a network of computers communicating with each other, rather than isolated centralized

information storage and processing machines, effort has been made to connect the computers together. Since different types of computers in different environments for different purposes are to be connected, various networks with different structures have been developed. In some networks, stations (i.e., computers and/or their peripherals, such as printers, etc.) are geographically close to each other, and dedicated channels, such as coaxial cables can be drawn between them. In other networks such as the ARPANET [22], stations are geographically dispersed and different kinds of channels, including dedicated lines and microwave links, etc., connect the network. In yet another type of network, physical dedicated channels, including dedicated lines and microwave links, etc., connect the network. In yet another type of network, physical dedicated channels cannot be drawn between the stations of the network, either due to geographical and economical reasons, or due to the mobility of the stations. In this case, radio channels can be used as the links in the network. However, the availability of radio channels are limited and several stations must share the same frequency bandwidth, giving rise to scheduling problems. Even if several radio channels were available, it would have been inefficient to assign a dedicated channel to a computer for communication purposes, simply because computers have very bursty traffic and therefore would not be able to fully utilize the assigned channel. In this thesis, we shall study these kinds of networks, generally known as Multiple Access Networks.

Victor Li's efforts on behalf on this thesis research, were supported in part by ARO.

* **Chung-Chin Lu**, "The Automorphism Groups of Binary Primitive BCH Codes", Ph.D. Dissertation, August 1987.

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ABSTRACT

For a long time, the usual tool used to find the entire automorphism group of a code is by exhaustive computer search. The goal of this thesis is to determine the entire automorphism group of any binary primitive BCH code by algebraic methods.

Two algebra structures in which cyclic codes have suitable representations are discussed. The Mattson-Solomon transformation which connect these two algebra structures has been studied thoroughly. A necessary and sufficient condition for a permutation to be an element of the automorphism group of a cyclic code has been found. From this condition, two corollaries which are most useful for binary primitive BCH codes are deduced. The automorphism groups of all 2, 3, 4-error-correcting binary primitive BCH codes have been classified. An infinite subclass of binary primitive BCH codes which have exceptional permutations for m even and not for m odd has been explored also.

It is observed that the automorphism groups of all binary primitive BCH codes worked out up to now are subgroups of the general linear group on the vector space F2m over F2. It has been shown that for almost all t-error-correcting binary primitive BCH

codes, $t \geq 2$, there are no exceptional permutation polynomials which are also linear isomorphisms other than traditional ones. A sufficient criterion for a linear permutation to be a leval permutation has been pointed out. It involves only manipulations of cyclotomic cosets. A table of legal linear permutations for m = 4, 5, 6, 7, 8, 9, 10, 11, 12 was obtained under this criterion. This table coincides with what was found up to now and has no more natural to pose three conjectures consecutively which lead to the determination of the automorphism groups of all binary primitive BCH codes.

Chung-Chin Lu was a full-time research assistant supported by ARO through 8/87.

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* **Kuo-Hui Liu**, "Binary Sequences with Very Small Local Partial Period Correlations and Local Orthogonal Sequences," Ph.D. Dissertation, August 1987.

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ABSTRACT

Sequences with the property of small local partial period correlation (LPPC) are desirable as code sequences in direct sequence spread spectrum systems. At first, we describe the structure of these sequences. Based on this particular structure, we are able to derive the necessary and sufficient condition for the existence of sequences with infinite periods which satisfy LPPC constraints. Properties of local partial period correlations of binary sequences with correlation +1, −1, or 0 are also studied. An algorithm which can generate all component sequences with good local partial period correlations is given.

This period of any binary sequence whose correlation over L symbols is 0 for time shifts 1 and 2 and for all starting points can be shown to equal L. In this degenerated case, partial period, L, is in fact full period. We call sequences with autocorrelations $R(t) = 0$ for $1 \leq |t| \leq TMAX$ local orthogonal sequences. Formula of the number of cyclic distinct local orthogonal sequences for $TMAX \leq 3$ are derived. Properties of binary sequences with $R(t) = 0$ for $t \neq 0 \bmod N/2$ are investigated. One special class of the above sequences are those with $R(N/2) = -N + 4$. The structures of these sequences are studied. We conjecture that all local orthogonal sequences with $TMAX = N/2 - 1$ and $R(M/2) = -N + 4$ can be generated by Wang and Welch's construction. From this construction, we can show that all odd length Barker sequences can be represented as quadratic residue transformation of multiple phase m-sequences.

A generalized construction method of sequences based on Wang and Welch's construction is given. This method can generate infinite classes of three-level-correlation binary sequences. One of these classes is consisted of sequences with period $N = 2(q^2 + q + 1)$, $R(t) = 2$ for $t \neq 0 \bmod N/2$ and $R(N/2) = -N + 4(q + 1)$ for any odd prime power q. These sequences minimize the maximum out of phase autocorrelation over all binary sequences with period $N = 2 \bmod 4$. Thus, they have potential applications in coherent

communication systems.

Kuo-Hui Liu was a full-time research assistant supported by ARO through 8/87.

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* **Stephen B. Wicker**, "A Geometric Approach to Error-Correcting Codes", Ph.D. Dissertaion, January, 1987.

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ABSTRACT

The relationship between error correcting codes and algebraic curves will be examined in this dissertation. We shall begin with a tutorial on the subject of classical algebraic geometry. This tutorial will provide the theoretical basis for the development of geometric models for the parity check and generator matrices of linear block codes. These models will be used to show the existence of codes which exceed the Gilbert-Varsharmov bound as demonstrated by Tafasman, Vladut, and Zink. Geometric methods will then be used to analyze the family of maximum distance separable codes and to provide a model for doubly-extended Reed-Solomon codes and other MDS codes of length q+1.

Lloyd R. Welch's efforts on behalf of this thesis research, were supported in part by ARO.

* **Sami Hinedi**, "Carrier Synchronization in Band-Limited Channels", Ph.D. Dissertation, March, 1987.

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ABSTRACT

Synchronization in a digital communication link is basically the distribution of frequency and time at both ends of the link. In the past three decades, the problem of synchronization in wideband channels has been studied extensively and many techniques have been proposed for achieving synchronization. Carrier tracking, suppressed carrier tracking or a hybrid of the two are basically the methods available to reconstruct a carrier reference from a noise-corrupted version of the received signal.

Today, the ever growing demand for more and more satellite channels has prompted users to increase the throughput of information through the existing channels. That sort of communication in a band-limited channel at a rate equal to or exceeding the channel bandwidth results in the spreading of the baseband pulse which in turn causes intersymbol interference (ISI). It is the objective of this thesis to study the effects of ISI on the tracking performance of conventional loops and to introduce new ISI mitigating loops to account for the ISI.

The major consideration in the design of the tracking loops is based on the ease of implementation and low cost of these loops. First a mathematical model for the communication channel is presented. To obtain explicit compensation techniques, Estimation theory is used to calculate the likelihood function of the phase when ISI is pre nt.

To evaluate the behavior of these ISI compensated loops, a set of performance measures is defined. Then using the mathematical model, the suppression factor is calculated for several loops eeith different synchronization techniques and the results are compared with other loops;

1. BPSK, QPSK, and the Unbalanced QPSK low signal-to-noise ration (SNR) carrier tracking loops are developed and their performances are evaluated.

2. Although only phase estimation is considered in this thesis, the effects of timing jitter on the tracking performance of the ISI compensated loops are discussed.

3. Even though independent data is assumed throughout the thesis, correlated data is also considered and its effect on the squaring loss is evaluated mainly for BPSK.

4. High SNR carrier tracking loops are also developed. Their performance is evaluated and compared to other loops.

5. The effect of ISI on the loop bandwidth is also addressed and evaluated for a first and a second order loop filter.

Finally, problems of synchronization for M-QPSK signals are pointed out and some measures are introduced to overcome these difficulties.

Sami Hinedi was a part-time research assistant, supported by ARO through 5/87

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* **Shen-Neng Chiou**, "Diversity Routing and Reliability in a Communication Network", Ph.D. Dissertation, December 1987.

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A B S T R A C T

The purpose of this dissertation is to study the effect of sending redundant copies of each message in a point-to-point communication network with unreliable components. To increase the probability of success, it is desirable to send the copies along edge-disjoint or vertex-disjoint paths. To study the trade-off between the increased reliability and the increased traffic load, the mean packet delay of the network is used. The use of delay as the performance measure takes reliability improvement and traffic increase of

two-copy schemes into consideration. In the delay analysis, we study the effects of network routing and retransmissions via a simple queueing model. The environment in which two-copy schemes achieve smaller network delay is discussed. We then formulate an optimization problem for two-copy routing under the special constraint of using a pair of disjoint paths for each transmission. The result is a nonlinear programming problem. We use two methods to solve it: the first belongs to the class of feasible direction of descent methods; the second belongs to the class of gradient projection methods. The seccnd method is easier to impelemnt in a distributed fashion.

Victor O.K. Li's efforts on behalf of this thesis research, were supported in part by ARO. Shen-Neng Chiou was a part-time research assistant supported by ARO 3/86-5/86.

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* **Kiseon Kim**, "Model-Based Detectors of a Sinusoid in Noise: Theory and Performance", Ph.D. dissertation, December 1987.

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A B S T R A C T

A problem of detection is considdered, which is widely useful to communication and signal processing field. The object of the detection problem is to decide whether there is a sinusoid with broadband additive Gaussina noise. The signal specification is not known except for the system bandwidth. As a compromise between complexity of the optimal and reduced performance of a simple radiometer, an autoregressive model is adopted for a received signal. Assuming that the model is exact and real coefficients are averaged values of sample coefficient values, cp. 2 suggests some model-based detectors from the likelihood ratio test and its approximation, which generalize and unify some detectors utilizing correlation values. Chapter 3 considers optimal detection, whose complex structure can be implemented variously with unknown variables modelled properly. Among suboptimal detectors in cp. 2, some detectors are chosed and are analyzed extensively, such as the simple correlation coefficient detector (cp. 4), the multiple correlation coefficient detector (cp. 5) and the autocorrelation detector (cp. 6). When the output of an autocorrelator is modelled as an autoregressive process, i.e. in C^2D domain, it is shown that the model based detectors are competitive to the spectral-maximum detector. Monte-Carlo simulation is performed for each statistic to validate the modelling, whose procedure is summarized at cp. 7 along with other mathematical tools.

Kiseon Kim was a full time research assistant, supported by ARO through 8/87.

* **Jeffrey C. Dill**, "On the Throughput of Multihop Receiver Directed CDMA Packet Radio Networks with Dynamic Random Topology", December 1987.

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A B S T R A C T

In this dissertation, the use of a Bernoulli random graph model is proposed for analyzing the performanc eof a specific class of land-mobile, dense, multihop packet radio networks. The Bernoulli model is justified throught he use of propagation modeling in rough terrain and heavy jamming. A simple channel access scheme is developed which uses receive directed CDMA and a slotted-ALOHA-like protocol for channel access. With the Bernoulli random graph assumption, a precise analytical model to predict network throughput as a function of the number of nodes and the network connectivity fraction is developed, assuming perfectly orthogonal spreading codes. A simple threshold model is also introduced to account for mutual interference when codes are not orthogonal. A detailed timeslot level simulation model, the multihop spread spectrum model (MHSS) is developed, and used to validate the nalytical model. The simulation model is subsequently used as an experimental tool to investigate adaptive algorithms and dynamic topological conditions, which are analytically intractable.

A dedicated channel acknowledgement protocol is developed with eliminates contention for acknowledgement transmissions, and also provides a vehicle for reliable routing updates. Adaptive algorithms for traffic homogenization are developed to alleviate traffic bottlenecks in the network and improve network throughput performance. This is achieved by adaptive routing according to minimum queue length, and also by adaptive transmission probability in the channel access protocol.

John Silvester's efforts on behalf of this thesis research, were supported in part by ARO.

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* **Phillip M. Feldman**, "Adaptive Hybrid ARQ Protocols for Discrete- and Continuous-Time Markovian Channels," Ph.D. Dissertation, December 1987.

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A B S T R A C T

This paper describes an adaptive hybrid ARQ protocol designed to maximize average throughput when used with channel subject to slowly-varying levels of noise, interference, or attenuation. We have used two Markovian channel models which allow for both time-varying noise levels and memory: a discrete-time channel model which applies to frame-synchronized multi-user systems and a continuous-time model which applies to unsynchronized systems. In both models, the channel has two states, each of which is characterized by some level of additive white Gaussian noise. Transitions between the states are described by a transition probability matrix.

The protocol adapts to changes in channel state, i.e., changes in noise level, by selecting one of two block error-correction codes. The two codes have different rates; if the channel is quiet, the throughput is higher with the high-rate code, and if the channel is noisy, the throughput is higher with the low-rate code. The code to be used for the next packet is selected according to an estimate of the next channel state; the estimate, based on the error pattern in the previous packet, is fed back to the transmitter via the

acknowledgment. For the continuous-time channel, we present an optimal state estimator. Because this estimator is computationally impractical, we develop a simple, suboptimal estimator which requires negligible computation and storage, and then develop an improved suboptimal estimator which performs almost as well as the optimal estimator.

We evaluate the average throughput and the complete transmission delay distribution (not only moments) for both the discrete- and continuous-time cases, and also investigate the throughput of the adaptive protocol in the presence of unanticipated interference (either CW or pulsed). Both throughputs and delay distributions were computed analytically, i.e., without the use of simulation, and in general involved no significant approximation. Detailed numerical results are presented; the results indicate the practical utility of adaptive hybrid protocols for communications applications to a broad class of channels subject to slowly-varying levels of noise, attenuation, or interference.

Phillip Feldman was a part-time research assistant supported by ARO 9/87-12/87. Victor Li's efforts on behalf of this thesis research, were supported in part by ARO.

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* **Jason S.J. Chen**, "Distributed Query Optimization in Fragmented Database Systems", Ph.D. Dissertation, August 1987.

* 1 copy 6/88

A B S T R A C T

Join is the most critical operation in distributed query optimization. In this thesis, the problem of optimizing multiple joins in fragmented database systems on both broadcast and nonbroadcast type computer networks is analyzed. Semantic information associated with fragments are used to eliminate unnecessary processing. Data redundancy is considered. Furthermore, we allow more than one physical copy of a fragment to be used in a strategy to achieve more parallelism.

In our proposed approach, the problem of optimizing multiple joins is decomposed into two subproblems: the problem of finding a good join sequence and the problem of optimizing each two-way join in the sequence. A dynamic programming algorithm is developed for determining a join sequence. During intermediate steps of the join sequence, we have the join results remaining fragmented to achieve more parallelism and allow more local executions. All the partial results are assembled at the last two-way join.

If the network has broadcast capability, graph models are introduced to represent two-way joins. The two-way join optimization problems are mapped into equivalent graph minimum-weight vertex cover problems. An algorithm based on network flow is developed for optimizing two-way joins with results fragmented. The two-way join optimization problem with results assembled is proved to be NP-hard. For nonbroadcast network environments, the problem of optimizing two-way joins either with results fragmented or with results assembled is also proved to be NP-hard.

For those NP-hard optimization problems, properties are identified to reduce the solution search space. Efficient heuristic procedures based on the identified properties are developed for suboptimal solutions. Theoretical bounds are provided to ensure the heuristic solutions are within a certain range from the optimal solutions.

Semijoins are also included in our approach. A new operation called domain-specific semijoin is introduced which can be performed in a fragment-to-fragment manner as opposed to a relation-to-relation or relation-to-fragment manner as in the application of regular semijoins. For a given query, there is always a strategy, using both domain-specific semijoins and semijoins, which is at least as good as the best strategy with only semijoins.

Shiaw-Juang Chen was a part-time research assistant supported by ARO 2/86-4/86. Victor Li's efforts on behalf of this thesis research, were supported in part by ARO.

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* **Sergio Aguirre**, "Digital Satellite Communications with Dual Polarization", Ph.D. Dissertation, December 1987.

1 copy 6/88

A B S T R A C T

This study is devoted to a comprehensive investigation of dual polarization digital satellite communications. The objective is to review existing propagation models developed by physicists with the eye of an engineer, assess performance degradations, consider crosstalk reduction techniques and alternative signal designs for combating depolarizaiton.

Depolarization and crosstalk assessment on dually-polarized links includes: error rate performance for uncoded Phase Shift-Keying (PSK), Continuous Phase Frequency Shift-Keying (CPFSK) and rate 2.3 coded 8PSK for independent links on each polarization with mismatched receivers.

Crosstalk reduction techniques include the design of maximum likelihood decoders (matched) with various degrees of channel conditions for the aforementioned modulation schemes. Crosstalk reduction also includes pulse shaping selection for jointly encoded signals over both polarizations.

Channel measurement techniques are discussed and evaluated. Two baseband adaptive channel parameter estimators are examined in detail; the complex LMS and the Recursive Least Squares. Finally, a tradeoff study of viable techniques for improving dually polarized communication links with depolarization is performed.

Robert Gagliardi's efforts on behalf of this thesis research, were supported in part by ARO.

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* **Jonathan Li-Jen Wang**, "On Some Design Optimization Issues in Packet-Switched Radio Networks", Ph.D. Dissertation, May 1988.

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1 copy 6/88

A B S T R A C T

Packet radio networks have become an effective means of data communications because the broadcast radio medium is a readily available resource, easily accessible, and particularly suitable for data communications among mobile users. The design of a packet radio network involves many complex interacting issues, with the result that no single model can capture all the system characteristics. In this thesis, we study some design optimization issues of packet radio networks, namely: protocol design, performance evaluation, and reliability.

For protocol design, we are concerned with protocols that are suitable for point-to-multipoint communication. This type of connection is receiving more attention lately because of the advent of applications such as teleconferencing, document distribution, and information systems. We first devise a two-level protocol which can be used in the network layer for the response traffic of broadcast messages. This protocol is designed to minimize system response time. Next, we devise an optimal adaptive ARQ protocol used in the dat alink layer for maintaining reliable communication between a single sender and multiple receivers. Under this protocol, the sender transmits multiple copies of a data frame in order to optimize some system performance measure such as throughput or delay. The optimum number of copies of the data frame that should be transmitted depends on the number of receivers that have not yet successfully responded.

For performance evaluation, we evaluate the maximum throughput that can be supported between a pair of nodes. In order to maximize throughput, we use a link activation protocol for data transmissions to avoid interference. Some simple conclusions can be drawn and serve as upper bounds for other multiple access protocols.

As to reliability, we define a new connectivity measure - *radio connectivity* which measures the vulnerability of packet radio networks operating in the presence of hostile jammers. The time complexity to find the radio connectivity between a pair of nodes is proved to be *NP*-hard. We therefore give two approximate algorithms to determine the radio connectivity. Radio connectivity also plays an important role in determining the maximum throughput that can be supported between a pair of nodes. This is not surprising, since network connectivity and maximum flow have direct relation in traditional line-based networks.

These results contribute to the development of designing techniques that achieve packet radio networks with high performance.

John Silvester's efforts on behalf of this thesis research, were supported in part by ARO. Jonathan Wang was a part-time research assistant supported by ARO 1/88-3/88.

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Technical Seminars

* C.L. Weber and A. Polydoros, "LPI Detection of Spread-Spectrum Waveforms", *GTE Seminar*, Mountain View, CA, September 5, 1985. (Abstract only.)

A B S T R A C T

Part I - DS and TH - Dr. C.L. Weber

The implementation and performance of wide-band detectors for direct-sequence and time-hopping spread-spectrum waveforms in the presence of additive white Gaussian noise are considered. Of interest is the performance penalty incurred when going from optimal to suboptimal detector structures. In both cases, performance is quantified by appropriately defined distance measures and is ultimately compared to that of the simplest hypothesis-discriminating device, namely, the energy detector (radiometer).

Part II - FH - Dr. A. Polydoros

Interception of frequency-hopping (FH) waveforms is commonly achieved by using a set of radiometers (energy detectors) which individually energy detect subbands of the total spread bandwidth of the suspected transmission. A scheme is analyzed which can improve the detection performance of FH waveforms in wideband additive Gaussian noise (AWGN) using samples from the autocorrelation domain. It is shown that, under fairly general operational assumptions, an appreciable gain in decision signal-to-noise ratio (SNR) can be achieved over that of the radiometer. This gain is proportional to γ_H is the hop SNR. The proposed algorithm, albeit inferior to the optimal likelihood-ratio test, has the advantage of reduced complexity.

The overall approach has been motivated by the recent implementational feasibility of large time-bandwidth-product real-time correlators such as surface-acoustic wave devices (SAWD's).

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* A. Polydoros, "Spectral Detection Algorithm for FH/LPI Signals", *GTE Seminar* presentation, Mountain View, CA, September 5, 1985. (Abstract only)

A B S T R A C T

The problem of detecting wideband spread-spectrum signals with unknown parameters in strong noise and/or interference is of current interest. Earlier approaches to this problem capitalized on the difference in the energy level between signal-plus-noise hypothesis (H_1) and the noise-only hypothesis (H_0), thereby utilizing an energy-measuring device (radiometer) as the key detection unit. Clearly, such a solution overlooks potentially known features of the sought signal and is, therefore, suboptimal.

In this talk, we shall review more advanced methods which clearly improve upon the radiometric approach. These new approaches include (1) optimal composite likelihood-ratio procedures, (2) suboptimal versions thereof, (3) the spectral-maximum or periodogram detector, (4) the recently discussed autocorrelation detector, and (5) certain baseband correlation algorithms, resulting from the AR or ARMA spectral modeling of the underlying process. Performance of each of those schemes is quantified either directly by

the associated (P_D, P_{FA}) pair or, indirectly, via an appropriately defined distance measure. Comparison of the resulting performance curves among themselves and with respect to the lower-bounding radiometric performance allows for certain conclusions to be drawn, depending on the desired region of operation.

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Technical News

Dr. Scholtz has presented the early development of spread-spectrum systems in Seminars at Hughes Aircraft Company and TRW, Inc.

Interest in ARO-sponsored work at USC has stimulated further contract from Army Laboratories:

Organization	Title	P.I.'s
Army Research Office Ft. Monmouth, NJ (Paul Sass)	Adaptive Spread Spectrum Networks	J. Silvester A. Polydoros
Army Research Office Warrenton, VA (Jim Mulligan)	Modulation Characterization Techniques	C. Weber A. Polydoros L. Welch
Army Research Office	Adaptive Channel Modeling Using Hidden Markov	R. Scholtz R. Peile
Army Research Office Workshop	Advanced Communication System Engineering	R. Scholtz

A US Army Research Office-sponsored workshop was organized in Sedona, Arizona, May 26-29, 1987. Attending from ARO were Dr. William Sander from Research Triangle Park, NC, and Drs. Charles Bosco and Randy Reitmeyer from LABCOM, Fort Monmouth, NJ.

Several industrial firms are taking a deep interest in communications research at USC and have joined the Communication Sciences Institute's Affiliates Program, which allows them to interact easily with our academic and research programs. These include Ford Aerospace, GTE, Hughes Aircraft Co., M/A-COM, Motorola, Pacific Bell, TRW, and for limited periods of time, Tadiran, Gould and Mitre. Dr. Weber and Dr. Polydoros have travelled to Mountain View, CA to give presentations to GTE engineers on our LPI research. Ph.D. candidates Wei-Chung Peng and Tsern-Huei Lee have also given presentations on the gaming approach to jamming to GTE engineers. Dr. Polydoros and Ph.D. student Kiseon Kim made a presentation to GTE on Mr. Kim's Ph.D. thesis research results. Drs. Weber and Scholtz have both made survey presentations of our work to meetings of Chief Engineers at Motorola's Government Systems Division in Phoenix, and Motorola. Dr. Ron Green of AIRMICS presently is considering the affiliation of his organization with CSI.

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Travel

* Robert A. Scholtz travelled to Brighton, England, to attend the *1985 IEEE International Symposium on Information Theory*, to deliver 2 technical papers, attend sessions and chair session B5, June 22-29, 1985.

* Robert A. Scholtz travelled to Cowichan Bay, British Columbia to be a *Panelist at Workshop on 'Research Trends in Spread Spectrum Communications'*, August 5-7, 1985.

* Charles L. Weber travelled to Cowichan Bay, British Columbia to attend technical sessions and deliver a presentation at the Workshop *Research Trends in Spread Spectrum Communications*, August 5-7, 1985.

* Robert A. Scholtz travelled to Boston, Massachusetts, to attend *MILCOM '85*, to chair a technical session and attend other meetings, October 21-15, 1985.

* John Silvester travelled to Palm Springs, CA, April 28-30, 1986, to attend and participate in the IEEE Communication Theory Workshop.

* Robert Scholtz travelled to Palm Springs, CA, April 28-30, 1986, to attend and participate in the IEEE Communication Theory Workshop.

* Charles Weber travelled to Palm Springs, CA, April 28-30, 1986, to attend and participate in the IEEE Communication Theory Workshop.

* Charles Weber travelled to Columbus, Ohio, and Kansas City, Mo., May 3-8, 1986,

  - to present a talk on "Acquisition in Wideband Communication Systems", at the Electrical Engineering Department at Ohio State University

  - and to attend the IEEE CAM Workshop, in Kansas City.

* Andreas Polydoros travelled to Boston, Massachusetts, May 16-20, 1986, to deliver a technical talk at Northeastern University entitled, "On the Wideband Detection of Sinusoids via Parametric Models".

* Victor O.K. Li travelled to Holmdel, NJ, and to Toronto, Canada, June 17-25, 1986, to deliver a seminar on "Fixed Assignment Retransmission, ALOHA Multiple Access Protocol," in Holmdel, NJ, and to attend and deliver 3 technical papers at IEEE, ICC '86, in Toronto, Canada.

* Robert Scholtz travelled to Monterey, California, October 5-8, 1986 to attend and participate in MILCOM '86, and deliver 3 technical papers.

* Andreas Polydoros travelled to Monterey, California, October 5-8, 1986 to

attend and participate in MILCOM '86, and deliver a technical paper.

* Robert Gagliardi travelled to Monterey, California, October 5-8, 1986 to attend and participate in MILCOM '86, and deliver 2 technical papers.

* John Silvester travelled to Warner Springs, CA, September 24-26, 1986 to attend the 1st Annual Computer Communications Workshop chaired and organized by himself.

* John Silvester travelled to Houston, Texas, December 1-4, 1986, to attend technical sessions and deliver a presentation at GLOBECOM '86. Partial travel was covered by this contract.

* Andreas Polydoros travelled to Boston, Massachusetts, November 15-18, 1986, to attend the Third IEEE ASSP Workshop on Spectrum Estimation and Modeling and present some research results.

* Dr. Victor Li travelled to San Francisco, CA, March 31 - April 2, 1987, to attend the IEEE INFOCOM, and deliver technical presentations. Partial support for his travel was provided by ARO.

* Dr. Victor Li travelled to Sedona, Arizona, May 26-29, 1987, to attend the ARO-CSI Workshop.

* Dr. Andreas Polydoros travelled to Sedona, Arizona, May 26-29, 1987, to attend the ARO-CSI Workshop.

* Dr. Charles L. Weber travelled to Sedona, Arizona, May 26-29, 1987, to attend the ARO-CSI Workshop.

* Dr. Lloyd R. Welch travelled to Sedona, Arizona, May 26-29, 1987, to attend the ARO-CSI Workshop.

* Dr. Victor Li travelled to Stowe, Vermont, Boston, MA, Bell Comm., NJ, IBM in NY, August 10-23, 1987:

  - To attend the ACM Conference,

  - To attend technical meetings at MIT,

  - To give an invited seminar at Bell Comm, NJ, and at IBM in NY.

* John Silvester travelled to Arlington, VA, April 11-13, 1988, to attend and present an invited talk at the Computer Networking Symposium.

* Robert Scholtz travelled to Sedona, Arizona, April 16-19, 1988, to attend and participate in the IEEE Communication Theory Workshop.

* Robert Gagliardi travelled to Sedona, Arizona, April 16-19, 1988, to attend and participate in the IEEE Communication Theory Workshop, and present a session talk.

COMMUNICATION SCIENCES INSTITUTE

ANNUAL REVIEW

Thursday, February 6, 1986

Room 1, Davidson Conference Center
University of Southern California

MORNING SESSION

A G E N D A

8:30 A.M.	**REGISTRATION**
9:00 A.M.	**Leonard M. Silverman**, *Dean of Engineering* - Welcoming Remarks
9:15 A.M.	**Dr. Charles L. Weber** - "Recent Results in: (1) Principles of Wideband Radar (2) A New Class of Algorithms for Soft Decisions of Linear Block Codes"
9:45 A.M.	**Dr. Irving S. Reed** "Adaptive Processing with Application to Optical Detection"
10:15 A.M.	**COFFEE BREAK**
10:45 A.M.	**Dr. Robert A. Scholtz** "Comments on a Variety of Jamming Problems"
11:15 A.M.	**Steve Mecherle** "Coding for the Semiconductor Optical PPM Communication System"
	Dr. Robert M. Gagliardi "Performance of Optical PPM Systems with Power Combining"
11:45 A.M.	**Dr. William C. Lindsey** "Network Synchronization and Applications"
12:15 P.M.	**L U N C H** - Faculty Center, Rooms B & C

AFTERNOON SESSION

A G E N D A

1:45 P.M.	**Dr. Solomon W. Golomb & Dr. Herbert Taylor** "Tuscan Squares – Theory & Applications"
2:15 P.M.	**Dr. Elvino Sousa** "On Distributed Spread Spectrum Packet Radio Networks"
2:45 P.M.	**COFFEE BREAK**
3:15 P.M.	**Dr. Victor Li** "Performance Comparisons of Acknowledgement Protocols for Multihop Spread Spectrum Networks"
3:45 P.M.	**Dr. Andreas Polydoros** "Research Summary of: (1) Code Synchronization (2) Wideband LPI Detection (3) Spread Spectrum Networks"
4:15 P.M.	**CONSULTATIONS**
6:00 P.M.	**COCKTAILS– University Hilton Hotel**
7:00 P.M.	**DINNER – University Hilton Hotel**

ATTENDEES - CSI Review 1986

John Armstrong
GTE

Stephen D. Stearns
GTE

Philip Fire
GTE

Patrick Wong
GTE

Roland Handy
Gould, Inc.

Richard Booton, Jr.
TRW

John Maul
TRW

J. Jay Jones
Ford Aerospace

Frank Chethik
Ford Aerospace

Edwin Key
MITRE Corp.

Ronald D. Haggarty
MITRE Corp.

Dean Carhoun
MITRE Corp.

Jawad Salehi
Bell Communications Research

Alex Netch
General Dynamics

James Spilker Jr.
Stanford Telecommunications, Inc.

William Sander
ARO

John F. Dillon
NSA

Eliza Wotaszik
RAND Corp.

Gilbert Devey
NSF

Barney Reiffen
MIT Lincoln Labs.

Fred Bond
Aerospace Corp.

Edward Bedrosian
RAND Corpn.

Roy Cideciyan
USC, Ph.D. Student

Robert Gagliardi
USC

Solomon Golomb
USC

Lloyd Griffiths
USC

P. Vijay Kumar
USC

Victor Li
USC

William Lindsey
USC

Steve Mecherle
USC Ph.D. Student

Jerry Mendel
Chairman, EE-Systems, USC

Andreas Polydoros
USC

Irving Reed
USC

Robert Scholtz
USC

Leonard Silverman
Dean of Engineering, USC

John Silvester
USC

Elvino Sousa
USC Ph.D. Student

Herbert Taylor
USC

Charles Weber
USC

Lloyd Welch
USC

COMMUNICATION SCIENCES INSTITUTE

ANNUAL REVIEW

Thursday, February 12, 1987

Room 1, Davidson Conference Center

University of Southern California

MORNING SESSION

A G E N D A

8:30 a.m.:	**R E G I S T R A T I O N**
9:00 a.m.:	**Dr. Leonard Silverman**, *Dean of Engineering* - Welcoming Remarks
9:15 a.m.:	**Dr. Robert Scholtz** "Developments at the Communication Sciences Institute"
9:30 a.m..	**Dr. Irving Reed** "Recent Thoughts on Detection Theory and its Applications"
10:00 a.m.	**Dr. Vijay Kumar** "On the Welch Bound"
10:30 a.m.:	**COFFEE BREAK**
11:00 a.m.:	**Dr. Lloyd Welch** "Automorphism Groups of BCH Codes & Simplified Decoding"
11.30 a.m.:	**Dr. John Silvester** "Recent Results in Packet Radio Networks"
NOON:	**L U N C H - Commons, Room B (upstairs)**
1.30 p.m.:	**Dr. James Yee** "Distributed Routing Algorithms for Communication Networks"
2.00 p.m.:	**Dr. Herbert Taylor** "Compatible Permutation Arrays with Good Correlation"
2.30 p.m.:	**B R E A K**
3.00 p.m.:	**Dr. William Lindsey** "Scintillation Effects on Communications"
3.30 p.m.:	**Dr. Paul Feintuch** "Some Current Sonar Issues"
4.00 p.m.:	**POSTER SESSION On Ph.D. Candidate Research**
6:00 p.m.:	**COCKTAILS - University Hilton, Room 1880**
7:00 p.m.:	**DINNER & ENTERTAINMENT**

POSTER SESSION - 1987

Student	Presentation Title
Alexovich, John	The Effect of Wideband High-Resolution Frequency Synthesizers on FSK-FH Communications
Chiou, Shen-Neng	Diversity Routing in a Communication Network with Unreliable Links
Ching, Chuang	On Power Spectral Densities of Modulated and Coded Digital Signals Via Markov Modeling
Chung, Habong	On the One-Dimensional Generalized Bent Function
Franz, Charles	An Analysis of Aperture Distortion Problems in an Airborne Real-Array Imaging Radar
Huey, Henry	Convolutional Codes Defined by Irreducible Polynomials
Kim, Kiseon	Wideband Detection in the Correlation of Correlation Domain
Kinman, Peter	Laser Doppler and Range Measurements with Active Transponders
Lee, Tsern-Hui	Communications with Multiple Data Rates in a Hostile Environment
Liu, Kuo-Hui	Binary Sequences with Very Small Local Partial Period Correlations and Local Orthogonal Sequences
Mayhew, Gregory	Statistical Properties of Modified de Bruijn Sequences
Pronios, Nikos	Slotted Random-Access Single-Hop Networks in Jamming
Rude, Michael	The P-Vector Algorithm: A Linearly Constrained Point of View
No, Jeong-Seon	On GMW Sequences
Tseng, Ching-Yih	VLSI Implementation on Generalized Sidelobe Canceller
Wang, Jonathon	On Some Optimization Problems in Packet Radio Networks
Wicker, Steve	The Geometry of Error Correcting Codes
Yang, Kun-Min	Adaptive Detection Algorithms for Optical Targets in Clutter
Yovanof, Gregory	Searching for Counterexamples to S. Piccard's "Theorem"
Yuan, Chin	Distributed Multiaccess Protocols for Integrated Voice/Data Traffic

CSI REVIEW - ATTENDEES

February 12, 1987

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COMMUNICATION SCIENCES INSTITUTE

ANNUAL RESEARCH REVIEW

Wednesday, February 10, 1988
Room 1, Davidson Conference Center
University of Southern California

A G E N D A

8:15 AM	**Registration**
8:45 AM	**Welcoming Remarks** - Robert A. Scholtz, Director of CSI
8:50 AM	**Networks Session**
	Overview of Networks Research in Electrical Engineering at USC - John Silvester
	Ballot Theory Applied to Code Division Multiple Access Networks - Victor O.K. Li
9:40 AM	B R E A K
9:55 AM	**Communication Systems Session**
	Frequency Synthesizer and Dual Polarization Study - Robert M. Gagliardi
	Communication Over Time-Varying Channels - William C. Lindsey
	Multiple Access Communications with Coding and Spreading - Andreas Polydoros
	Optical Communication Receiver Study - Charles L. Weber
10:55 AM	B R E A K
11:10 AM	**Panel Discussion** - Issues and Opportunities in Telecommunications Research and Education
	Moderator: R. A. Scholtz, Director CSI
	Participants: Solomon W. Golomb - Vice Provost for Research, USC
	Lloyd R. Griffiths: Associate Dean for Research, USC School of Engineering
	William C. Lindsey: Professor of Electrical Engineering
	Jack Munushian: Director, Instructional Television Program
12 NOON	Lunch at the Faculty Center
1:30 PM	**Coding/Signal Design Session**
	Recent Results on Sequences and Codes: An Overview - P. Vijay Kumar
	Sequences with Special Correlation - Solomon W. Golomb

	Applications of Error-Correction Coding - Robert Pelle
2:30 PM	B R E A K
2:45 PM	**Detection/Estimation Session**
	A Brief Overview of Detection/Estimation Applications at CSI - Charles L. Weber
	An Introduction to Modulation Characterization - Charles L. Weber
	Likelihood Ratio Considerations in LPI Detection/Modulation Classification - Andreas Polydoros
	Optimal Detection of a Linear Combination of Signals - Irving S. Reed
3:45-5:45 PM	**Poster Session**
4:00 PM	**CSI Advisory Board Meeting** - Davidson Conference Center Room 222
6:00 PM	**Mixer** - Ballroom West, University Hilton
7:00 PM	**Banquet** - Ballroom West, University Hilton

POSTER SESSION - 1988

Sergio Aguirre	Signal Design for Dual Polarization Digital Communication
Habong Chung	Optical Orthogonal Codes
Jeff Dill	Spread Spectrum Packet Radio Networks Anastasios Economides Decentralized Adaptive Routing
Yu-Cheun Jou	Bent Sequence Generator Design
Farhad Khansefid	Sets of Zero-One Sequences with Good Auto- and Crosscorrelation
Kiseon Kim	Detection/Classification for MPSK Signals: Low Input SNR Case
Seok-Ho Kim	Filter Design for Chip Rate Detectors
Kurt Kosbar	Pseudonoise Code Tracking
Khiem Le	Cause-Based Reliability Model for Dependent and Multimode Failures
Ji-Chien Lee	A New Recursive Moving-Target Detection and Tracking Algorithm
Chao-Ming Liu	Elliptic Algebraic Geometric Codes
Yeeman Lo	Satellite Communications in the Scintillation Channel
Merdad Madavi	Performance of Digital Communications in the Presence of Oscillator Instabilities
Jong-Seon No	A New Family of Binary Pseudorandom Sequences Having Optimal Correlation Property and Large Linear Span
Thomas Papavassiliou	On Some Topological and Routing Issues in Multihop Spread Spectrum Networks
Nikos Pronios	Diffusion Approximation for Throughput/Delay Analysis of Slotted Random-Access Networks
Cheng Song Wu	Received Initiated Busy Tone Multiple Access
Ming Yin	Throughput Analysis of Asynchronous CDMA Networks
Gregory Yovanof	The Inverse Problem, Homometric Structures, and Combinatorial Designs
Xiaoli Yu	Detection of Moving Targets Using GMLR Test Algorithm
Ning Zhang	Generalized Barker Sequences

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Lloyd R. Welch	Co-Principal Investigator

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